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STRESS ANALYSIS OF THE LHA-1 CLASS SUPERHEATER HEADER BY FINITE ELEMENT METHOD

by

Jon W. Kaufmann

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Thesis Advisor G. Cantin
Co-Advisor E. L. Wilson

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Stress Analysis of the LHA-1 Class Superheater Header by Finite Element Method

by

Jon W. Kaufmann
Lieutenant, United States Navy
B.S., State University of New York Maritime College, 1981

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Numerous cracks and leaks in the superheater header tube attachment welds in the LHA-1 class of amphibious assault ships have prompted an investigation by the Naval Sea Systems Command (NAVSEA). This thesis describes the stress analysis of the superheater header tube attachment region using a three dimensional axisymmetric Finite Element model. The SAP 80 structural analysis program was utilized to conduct the analysis. Both pre and post processors were employed to obtain graphical representations of the model as well as the results of the stress analysis. This thesis focuses primarily on thermally induced stresses produced in the header. Some results obtained for a nominal 100 Degree F temperature drop across the thickness of the superheater header wall yielded a maximum hoop stress of 19.01 (Ksi) and a maximum in plane stress of 1.58 (Ksi).

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I. INTRODUCTION

Over the past five years the United States Navy has experienced an unusually large number of failures of the superheater header tube attachment weld utilized in the Combustion Engineering Co. model V2M marine boiler which is installed aboard the LHA-1 class of amphibious assault ships. The Naval Sea Systems Command (NAVSEA) began an investigation to determine the cause of the failure and any possible solutions to the problem. Part of the investigation included an extensive instrumentation of the No. 2 main boiler installed aboard the USS Belleau Wood (LHA-3) for the purpose of determining thermally induced stress information applicable to an LHA-1 Class header model. The instrumentation included thermocouples , strain gages and dial indicators.

During March 1986 the USS Belleau Wood conducted underway operations at various speed and load conditions while the installed instrumentation coupled with an automated data acquisition system recorded temperature, strain and displacement data for the header. Data for the following plant load conditions was recorded:

- cold lite-off cycle (approx. 4 Hrs.)
- 25 % steady state boiler operation
- 50 % steady state boiler operation
- 75 % steady state boiler operation
- 90 % steady state boiler operation

Data readings were recorded automatically at 15 minute intervals during each of these conditions. Details of the instrumentation location and sample data are included as Appendix A.

Despite the extensive amount of temperature data which was recorded, only a limited amount of data was available in the region of the header which was modelled since there were only three thermocouples installed in the local region of the header tube attachment weld.

A Finite Element model of the header was developed using the SAP 80 structural analysis program. Using the model which was developed, a study was made of the effects of thermal gradients on the stresses experienced in the header. A discussion is also included of some of the factors which introduce some non-linearities into the

problem, such as the consideration of temperature dependent material properties and the effects of creep on the structure at the elevated operating temperatures which are experienced.

II. DETAILED DESCRIPTION OF THE PROBLEM

The V2M marine boilers installed aboard the LHA-1 class of ships are two drum, natural circulation "D" type boilers manufactured by the Combustion Engineering Co. Two boilers, one left hand and one right hand are installed in the main engine rooms as shown in Figure 2.1. Each boiler has an integral superheater and extended surface economizer. The boilers are designed to produce superheated steam at 628 Psi at 904 Degrees F at the superheater outlet under full rated conditions.

A. SUPERHEATER DESCRIPTION

The superheater raises the temperature of the saturated steam leaving the steam drum. Superheating the steam is a means of increasing the efficiency of the boiler as well as preventing erosion of the turbine blades. The superheater is made up of 268 "U" shaped tubes which are inclined from the vertical. The 268 tubes are arranged in 67 rows with each row containing four tubes. The tube elements terminate in two headers at the bottom of the boiler, as shown in Figure 2.2. One header is designated the inlet/outlet header while the other is designated the intermediate header. Diaphragms in the inlet/outlet header and the intermediate header divide the superheater into four passes as shown in Figure 2.3.

Tube elements are contact rolled into holes in the headers. The holes are counterbored and the elements are seal welded to the header in the counterbores. The tubes are 1.5 Inch OD X 0.12 Inch minimum wall thickness, seamless 2.25 Chrome tubing (MIL-T-16286, Class E). The headers themselves are 12.75 Inch OD X 2 Inch minimum wall thickness, 2.25 Chrome pipe (ASME-SA-335, Grade P-22). The headers are flattened on top to widen the area where the tubes are attached. There are 23 elliptical handholes in each header on the side opposite to the tube holes. These holes provide access for inspection and seal welding.

The superheater elements are supported from the headers which have support saddles at each end. The alignment of the tubes is maintained by attachment to the third row of screen tubes on one side and the fourth row of 2 Inch tubes at the entrance to the generating bank. This attachment is made by the use of attachment lugs as illustrated in Figure 2.3.

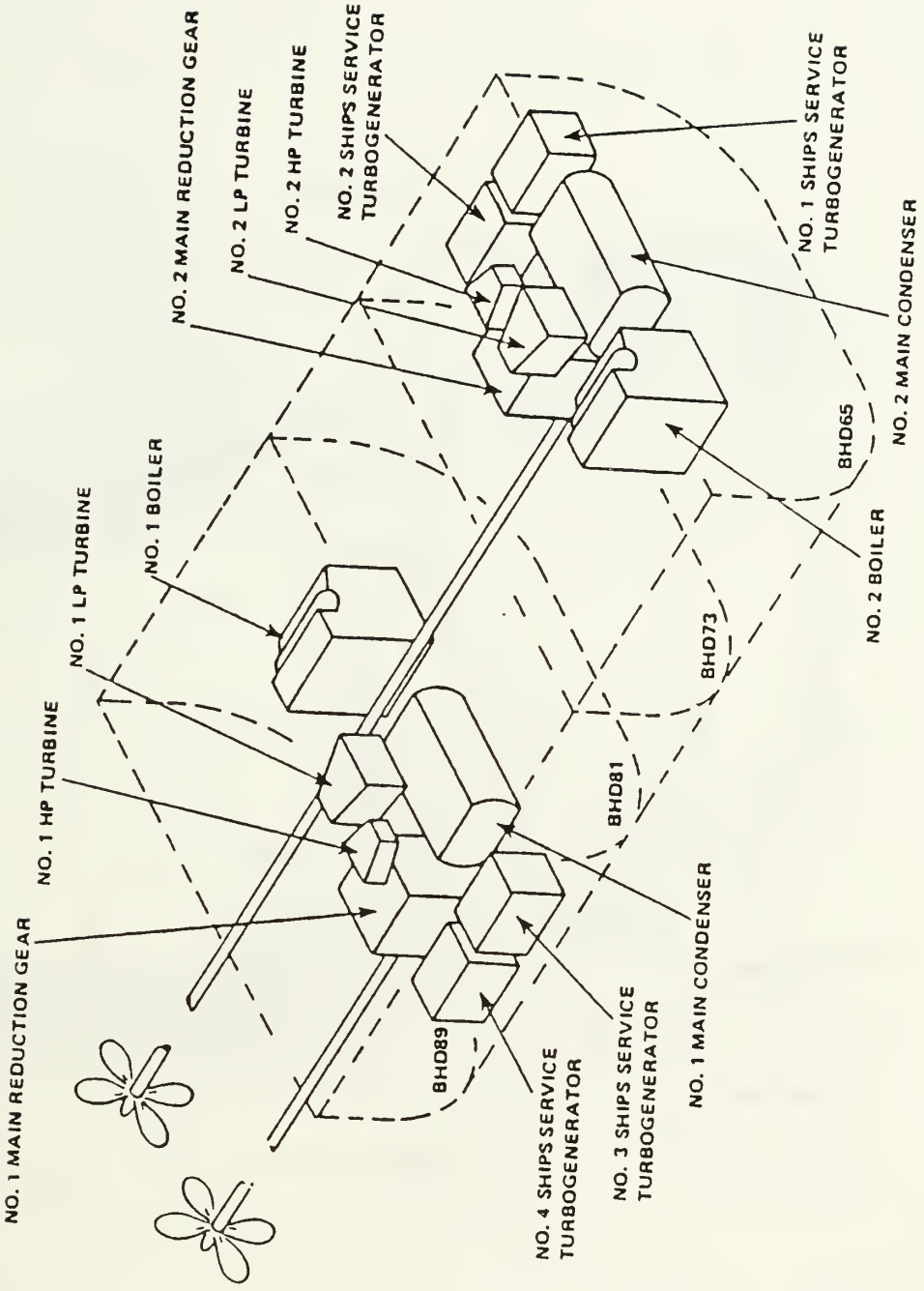


Figure 2.1 LHA-1 Class Main Engineroom Layout.

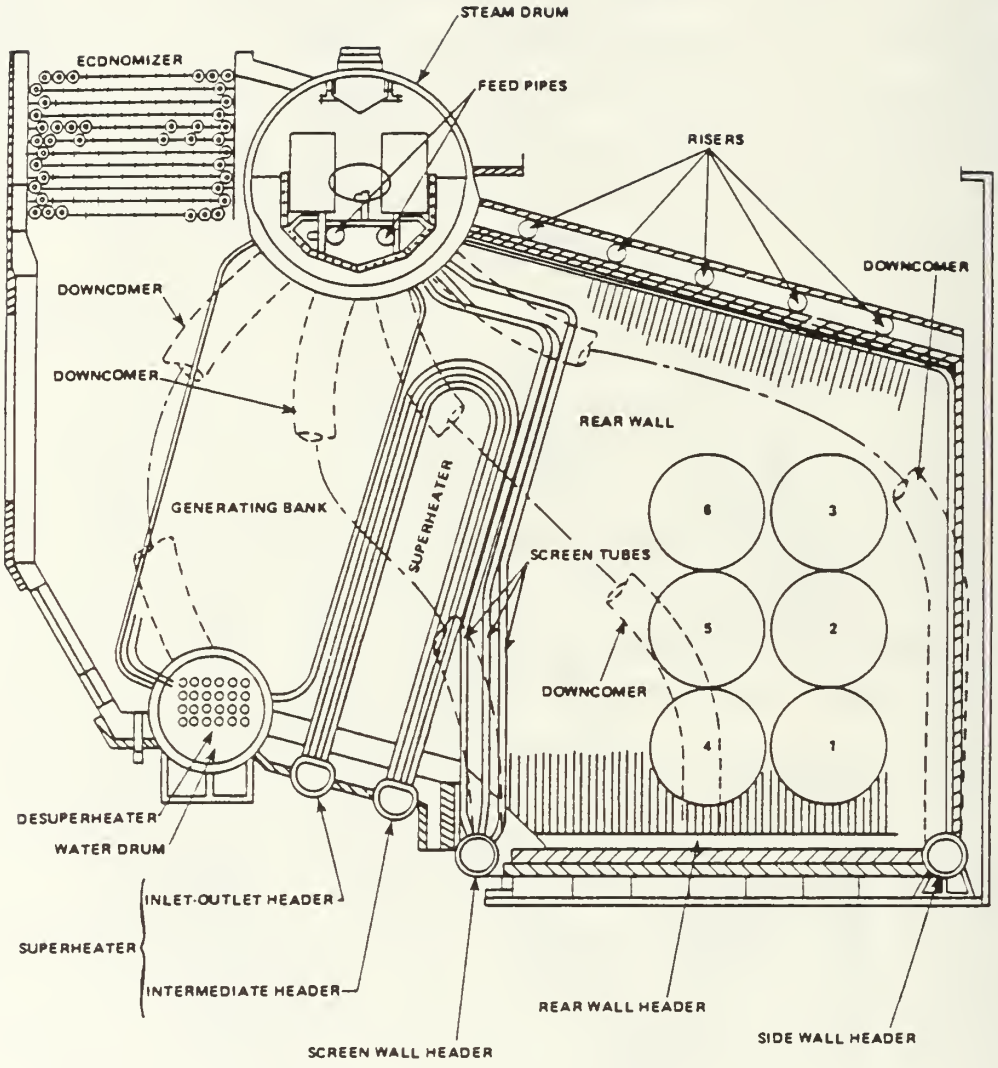


Figure 2.2 Side View of the V2M Marine Boiler.

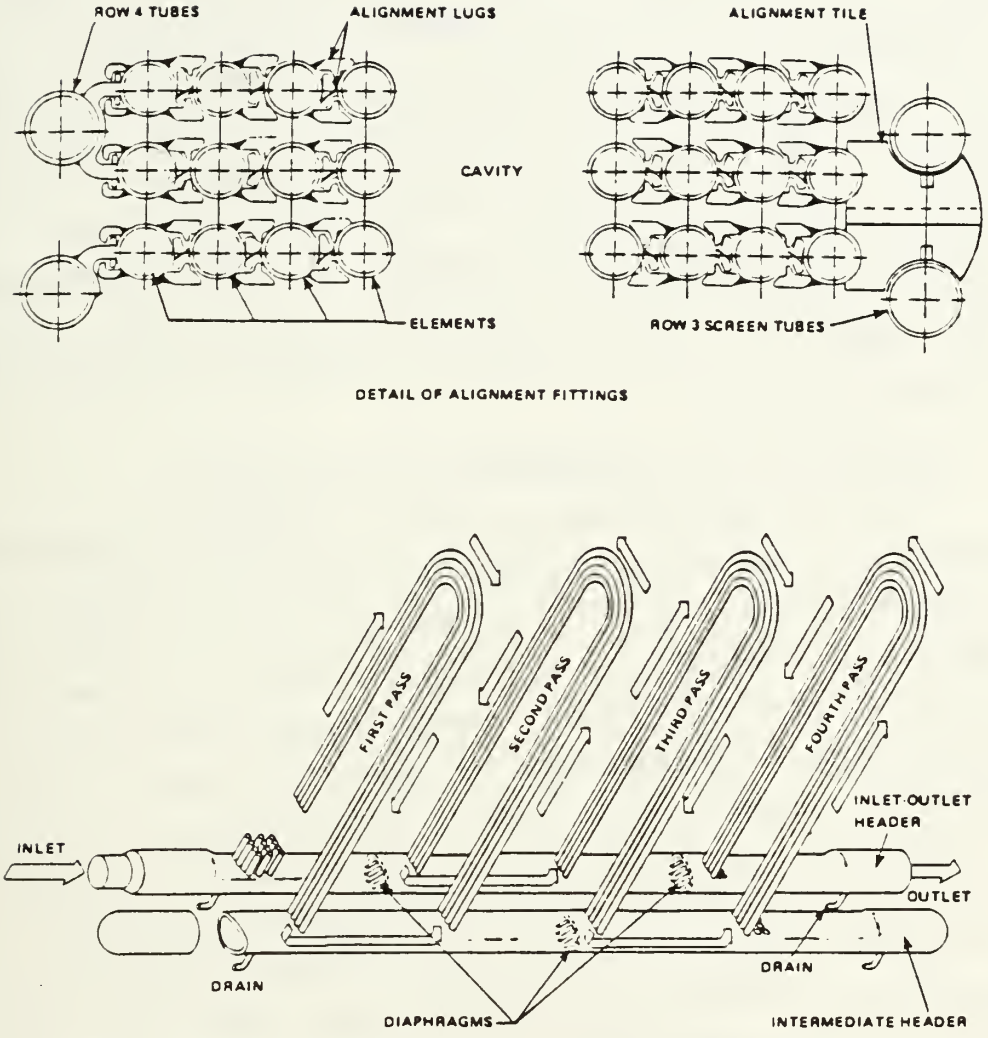


Figure 2.3 Four Pass Superheater Schematic and Alignment Lug Orientation.

B. GEOMETRIC DESCRIPTION OF THE HEADER/TUBE ATTACHMENT REGION

Figure 2.4 illustrates a cross section view of the superheater header which shows the orientation of the tube holes. The counterbore dimensions are indicated on the drawing as well as the arrangement of the tubes with respect to the header. Figure 2.5 offers an expanded view of the header/tube attachment region. As shown, the counterbore has a 1/8 Inch radius of curvature. It should be noted that Figure 2.5 is not to scale and therefore offers a distorted view of the region. Using the dimensions provided in Figure 2.5, Figure 2.6 was then constructed to scale using a scale of 30.449:1. Figure 2.6 was utilized to obtain the coordinates needed to define the geometry of the region for modelling purposes. The shape of the top surface of the weld is restricted not to exceed 1/16 Inches above the surface of the header in [Ref. 1: Page A-18]. As shown in Figure 2.6, a circular arc was chosen to describe the top surface of the weld.

C. DESCRIPTION OF OBSERVED SERVICE FAILURES

The most complete information compiled by NAVSEA concerning failures of the joint in question was obtained after removal of the superheater headers from the USS Tarawa (LHA-1). Figures 2.7, 2.8, 2.9, 2.10 and 2.11 are photographs which were taken after the header was split longitudinally in order to reveal the surface of the welds on the inside of the header. Following removal, magnetic particle tests were performed to detect any cracks which were present in the header. A summary of the results from the magnetic particle tests are illustrated in Figures 2.12, 2.13 and 2.14. The results of the magnetic particle tests showed that there was no particular pattern to the location of the failures. However, as the figures show, the failures seem to be more frequent towards the ends of the header. This fact would tend to discount the hypothesis that the failures were caused by a sagging condition of the header due to the fact that the two saddle supports for the header are located at the inlet and outlet ends of the header. If this hypothesis was correct one would expect to see the failures concentrated in the center region of the header since the stresses produced by sagging would be a maximum in this region. During the examination, it was also discovered that a large percentage of the welds were actually bridged to adjacent welds by excess weld material.

Findings from the USS Tarawa's headers indicated that *all* of the failures appeared to occur in the weld material, and that the most common mode of failure was

a radially oriented crack in the weld material. More detailed metallurgical inspections of the failure surfaces revealed a significant amount of corrosion. The pattern of the corrosion indicated that the failure took place in a progressive manner over a relatively long period of time.

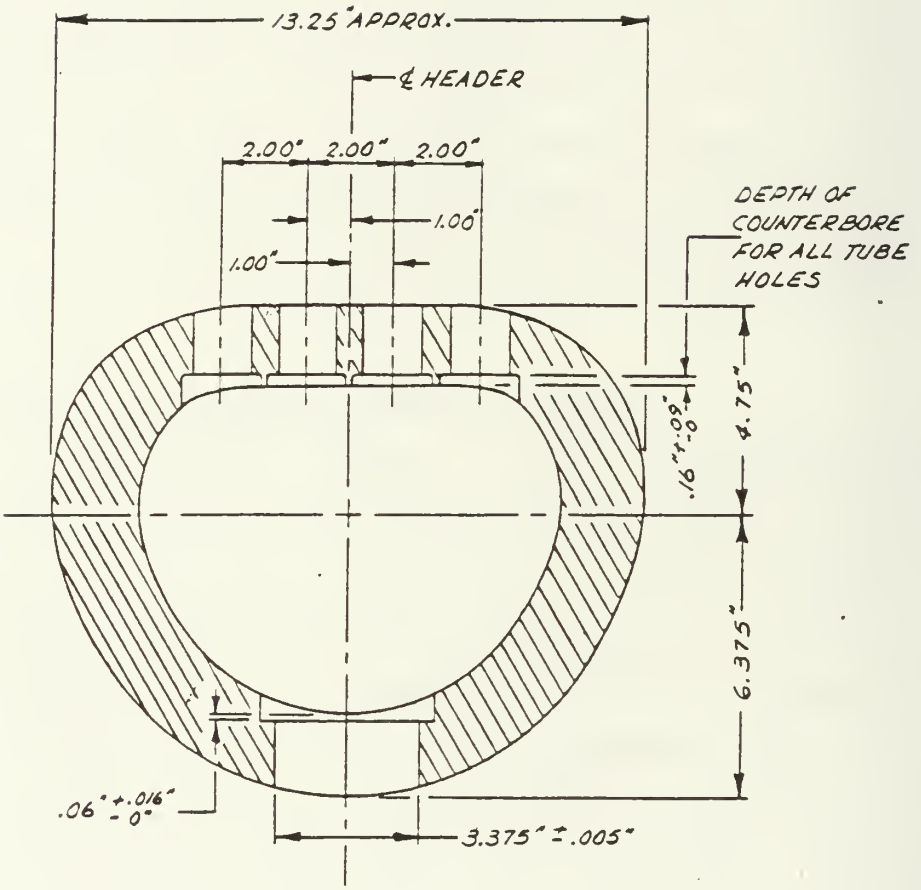
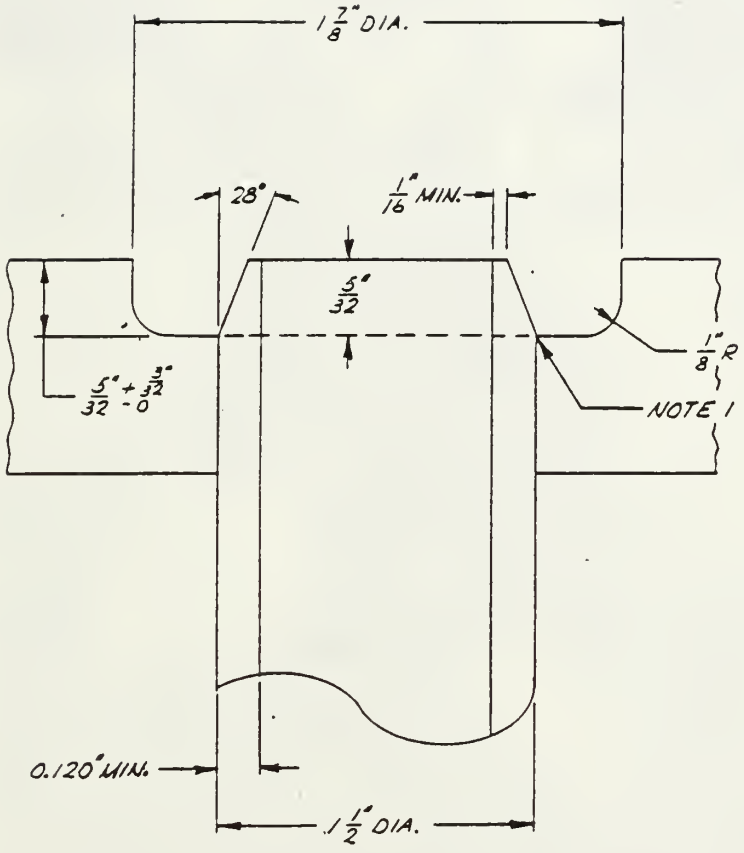


Figure 2.4 Superheater Header Cross Section.



NOTE:
1. TUBE IS POSITIONED SUCH THAT BASE OF TUBE CHAMFER IS FLUSH WITH SQUARE CORNER AT BOTTOM OF COUNTERBORE AS SHOWN

Figure 2.5 Detail of Superheater Header Tube Attachment Weld Joint
NOTE: Drawing Is Not To Scale.

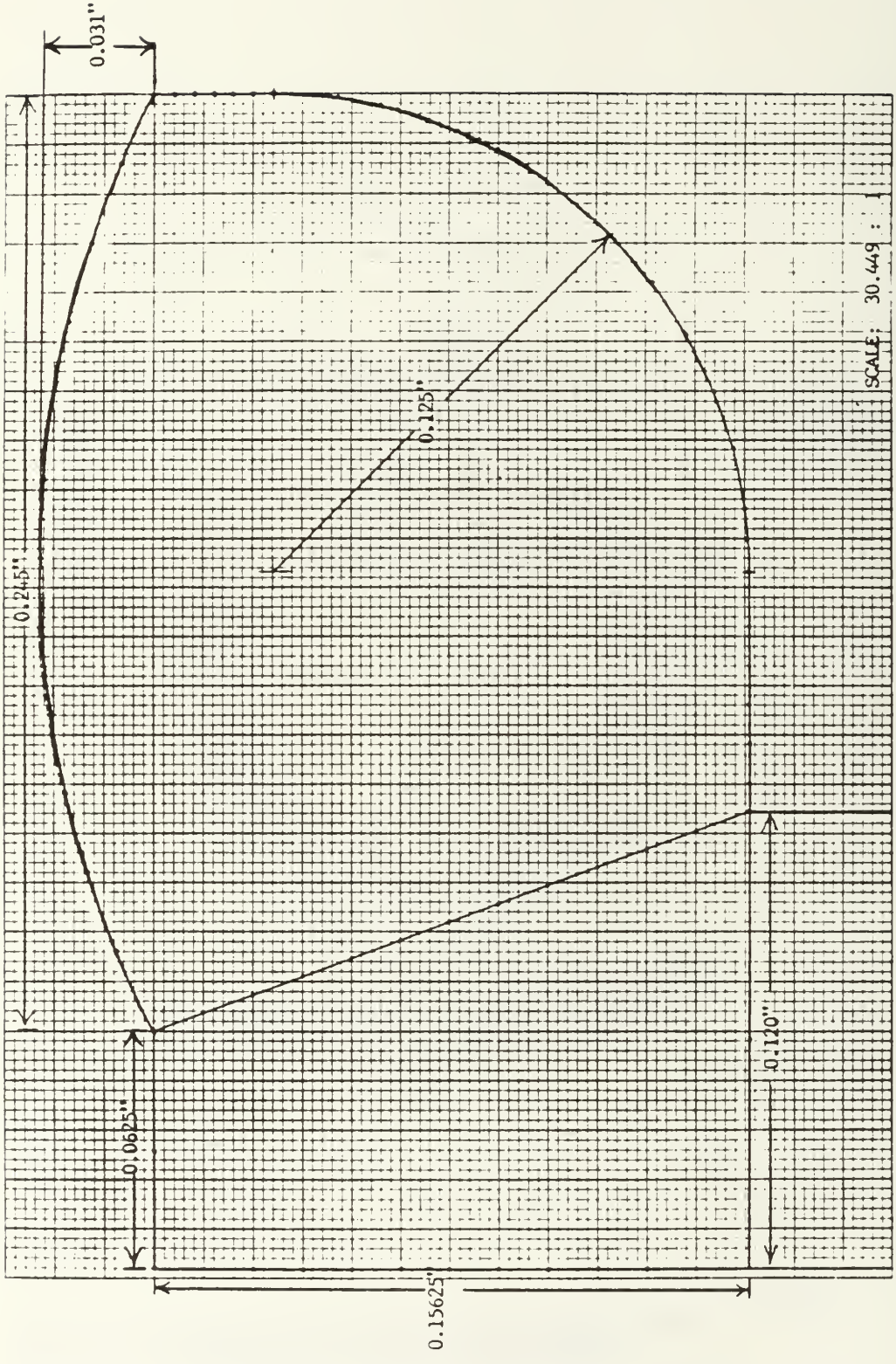


Figure 2.6 Plot of Constructed Weld Geometry for Modelling Purposes.

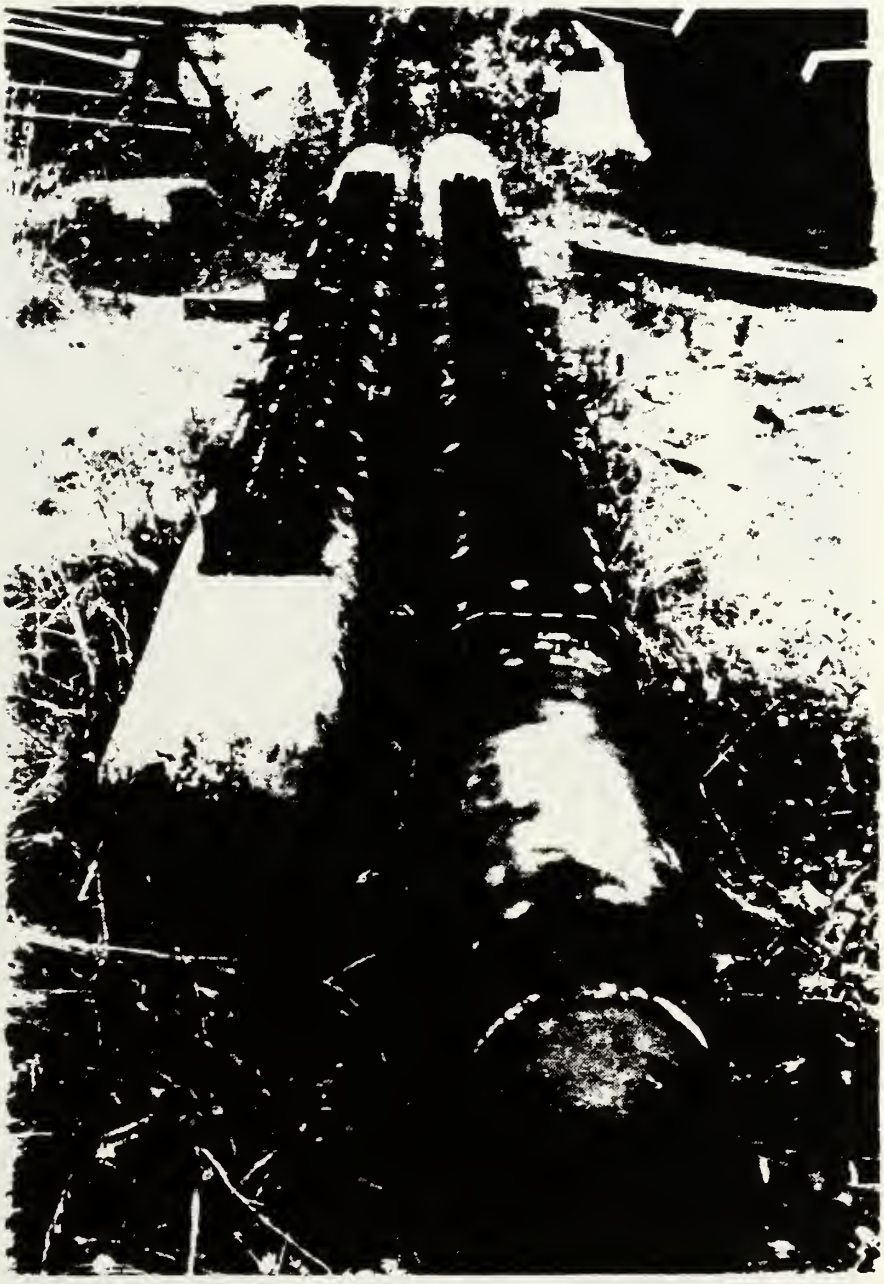


Figure 2.7 Intermediate (left) and Inlet Outlet (right) Superheater Headers After Removal From USS Tarawa (LHA-1).

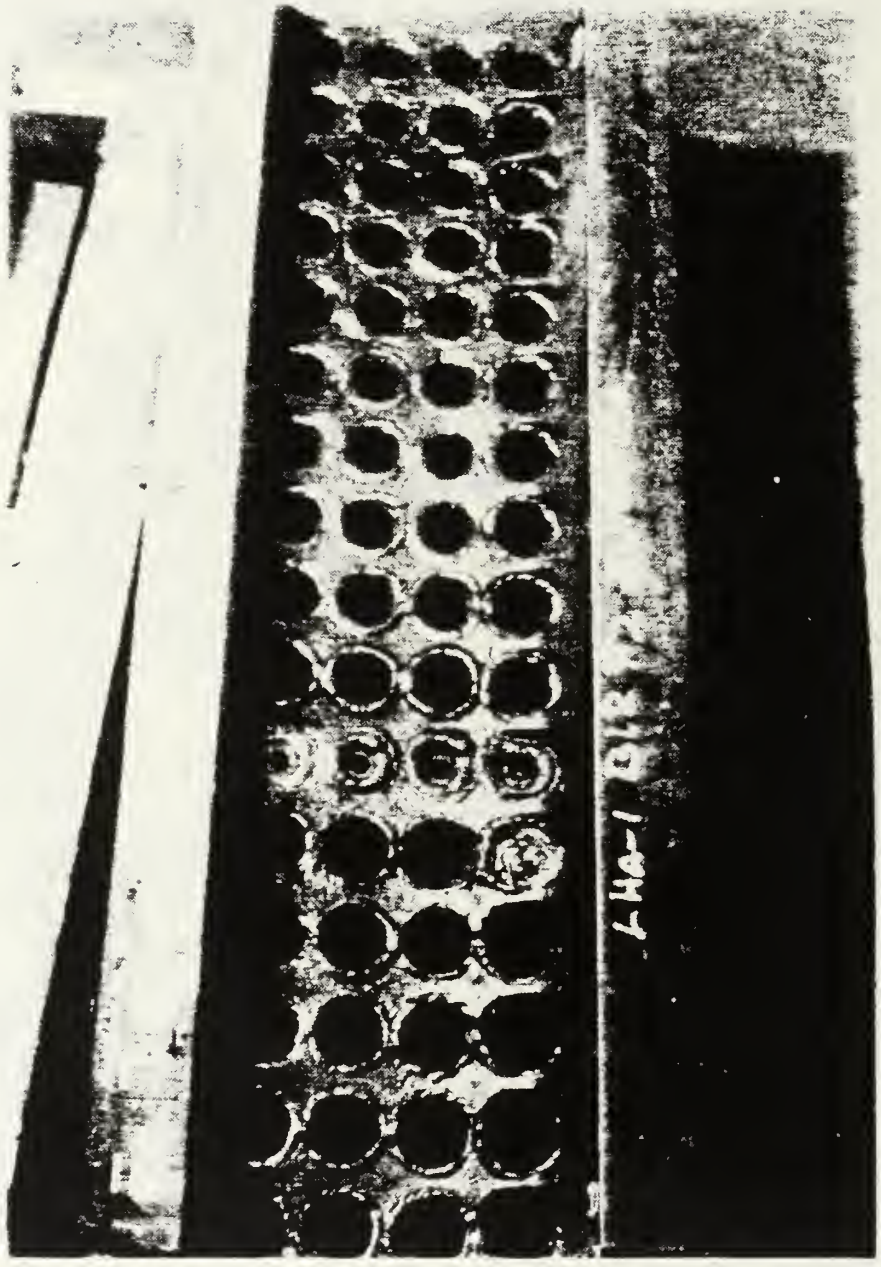


Figure 2.8 USS Tarawa Intermediate Header Prepared for Inspection.

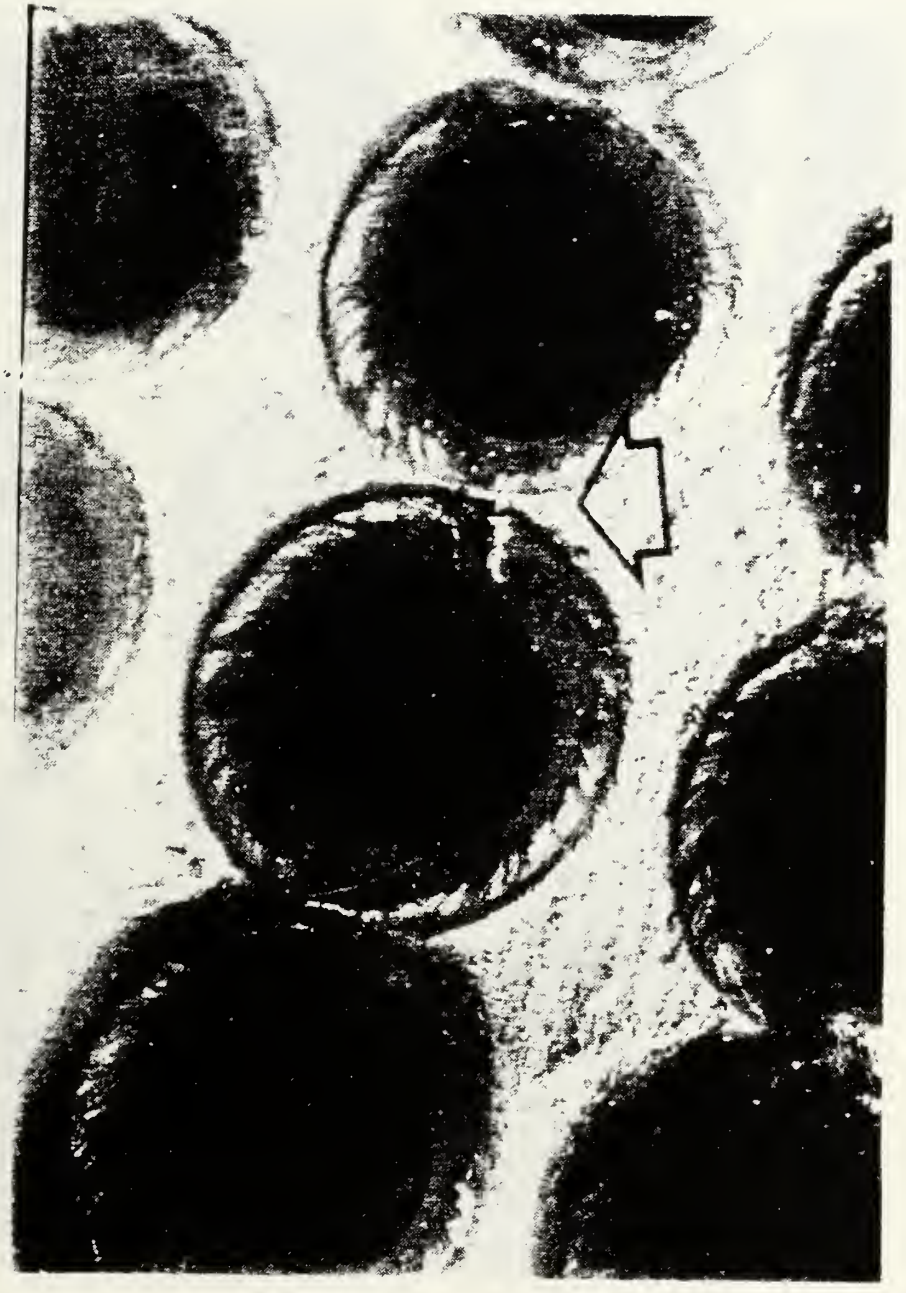


Figure 2.9 Magnetic Particle Indications of Transverse Weld Cracks In No. 2 Boiler Intermediate Header.

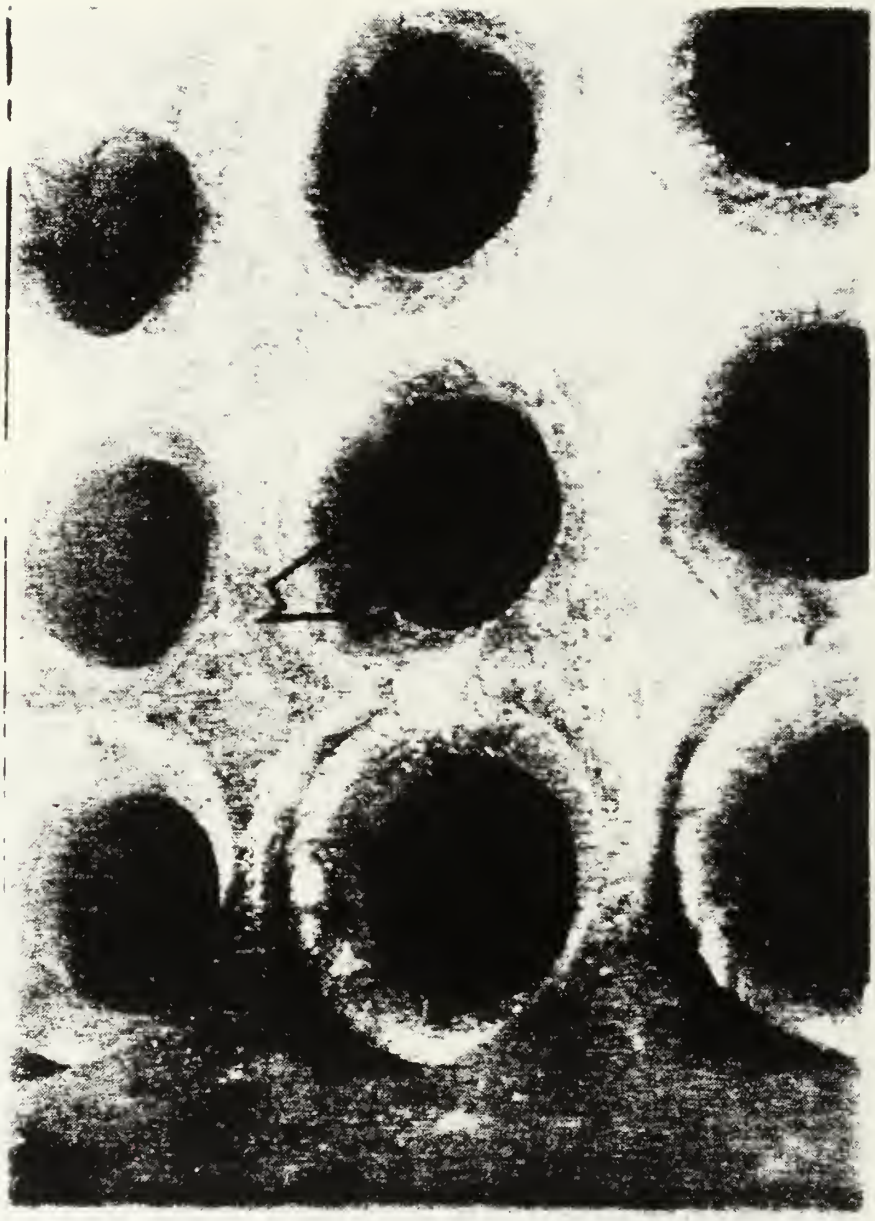


Figure 2.10 Magnetic Particle Indications of Ligament Cracks in No. 1 Boiler Inlet Outlet Header.

Figure 2.11 Magnetic Particle Indication of Crack in Weld in No. 2 Boiler Intermediate Header.

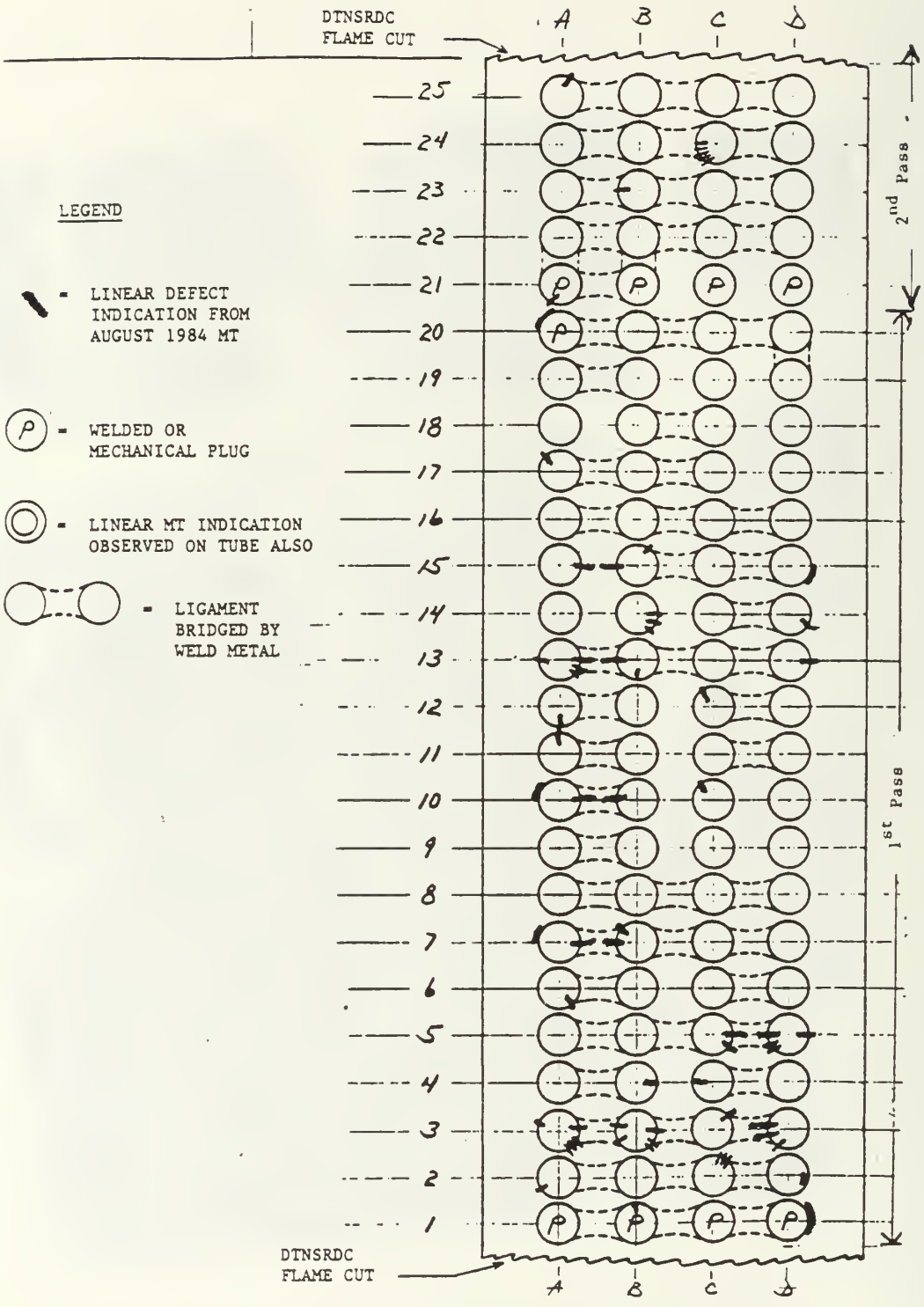


Figure 2.12 Magnetic Particle Test Results (Rows 1 - 25).

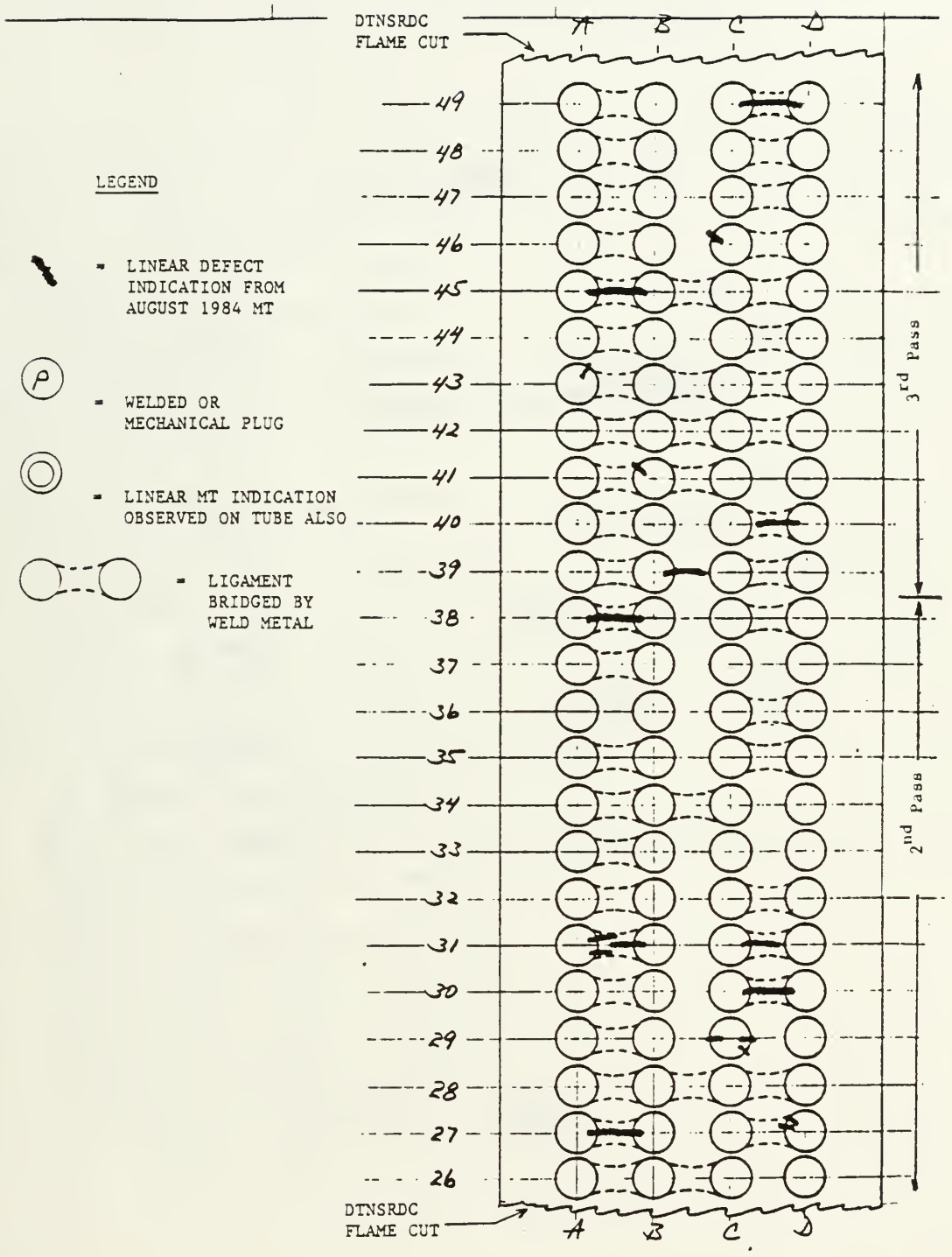


Figure 2.13 Magnetic Particle Test Results (Rows 26 - 49).

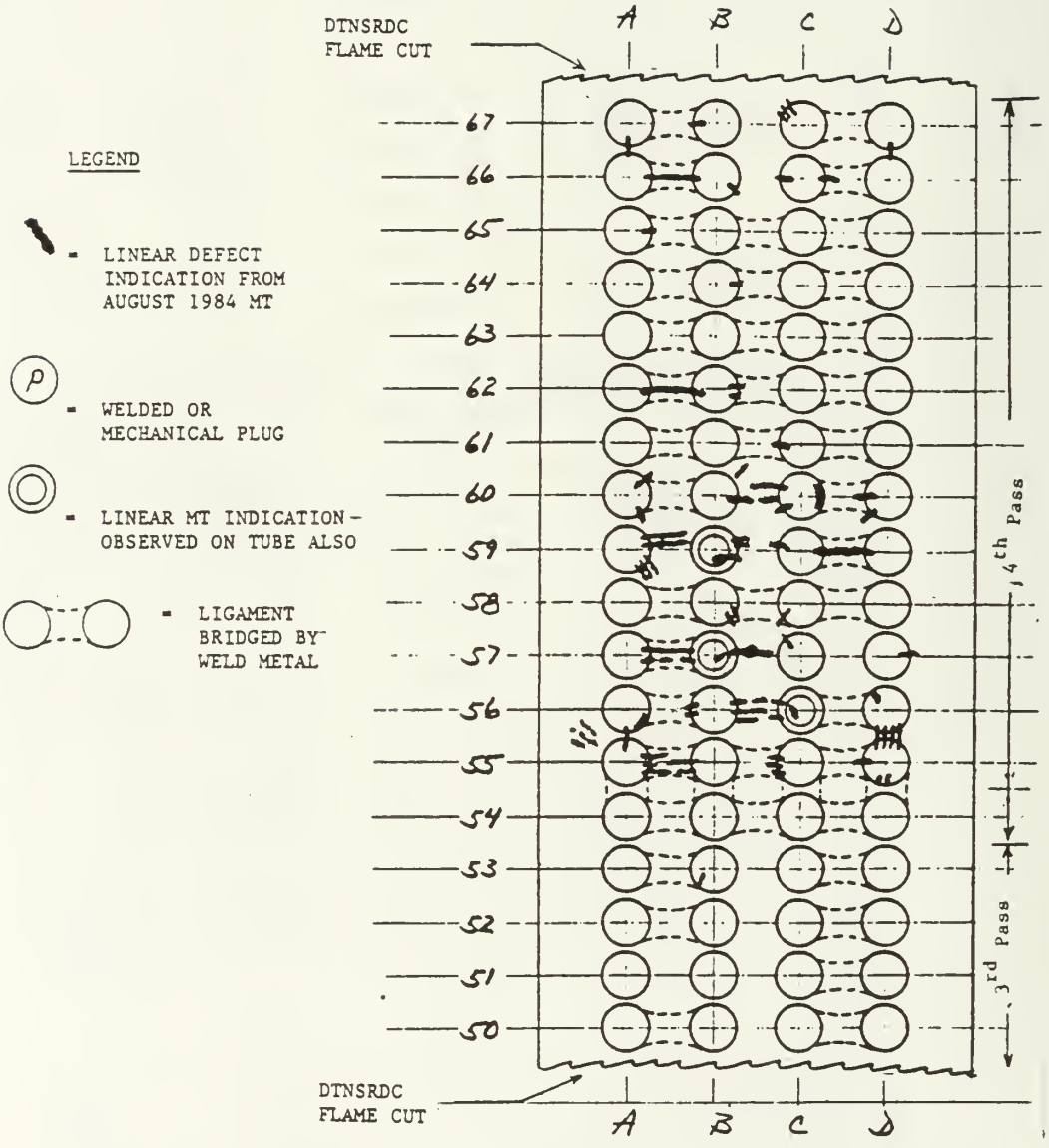


Figure 2.14 Magnetic Particle Test Results (Rows 50 - 67).

III. GENERAL DESCRIPTION OF SAP-80

The SAP-80 structural analysis program is actually a series of computer programs for the static and dynamic Finite Element analysis of structures. The program was developed by Professor Edward L. Wilson of the University of California at Berkeley.

A. METHOD OF SOLUTION

For static analysis of the isoparametric problem, SAP-80 solves the following node point equilibrium equation as developed in [Ref. 2: page 163]:

$$K\ U = R \qquad \text{(eqn 3.1)}$$

where:

- K = Union of all the element stiffness matrices
- U = Unknown node displacements
- R = Load matrix which includes concentrated nodal forces, body forces, surface forces and the initial forces.

The stiffness matrix is defined in equation 3.2 :

$$K = \int B^T C\ B\ dV \qquad \text{(eqn 3.2)}$$

where:

- B = Strain - Displacement Transformation Matrix
- C = Constant Material Property Matrix (Stress-Strain Relationship)

The elements of B are functions of the natural coordinates r,s and t being derived from the isoparametric representation of displacements and the inverse of the Jacobian matrix. The integration is carried out in the natural coordinate system of reference, and dV is defined as:

$$dV = \text{Det}(J)\, dr\, ds\, dt \qquad \text{(eqn 3.3)}$$

where:

- Det(J) = Determinant of the Jacobian Matrix

The integration is accomplished using Gauss quadrature and the resulting matrix is stored in compacted form.

B. PRE AND POST PROCESSOR CAPABILITIES

Pre and post processing for the SAP-80 system is included in the "SAPLOT" program. SAPLOT is an interactive geometric plotting pre and post processor. The program has options for plotting two and three dimensional views displaying any of the following:

- Undeformed structural geometry
- Static analysis deformed shape
- Steady state analysis deformed shapes
- Mode shapes

The model may be viewed from any arbitrary direction. The user locates any arbitrary point with respect to the Global X, Y, Z coordinate system. This point is called the view control point. The view is set in the direction pointing away from the view control point and towards the SAP-80 Global origin. The actual location of the viewer's eye is assumed to be at infinity. Once the view direction is set, the user can rotate the view by specifying which of the SAP-80 Global axes is to appear vertically upward on the screen.

When displaying the deformed shape of the structure, the user may also plot the undeformed shape with dashed lines. The user can also set the maximum values for displacements in order to accentuate the structural deformation. The deformed shapes

of elements may be plotted with displaced straight lines or with cubic curves. The program also has an option which allows the elements to be shrunk about their centroids, thereby clearly displaying element connectivities and uncovering any overlapped element boundaries. This is called the "element shrinkage" option.

The program has a "window" option which allows the user to display "blowup" images of localized regions within the structure. The program also has the capability to label node points as well as element numbers.

C. FINITE ELEMENT MODEL DEVELOPMENT

After review of the information available concerning the failure of the header tube attachment weld, it was decided to model the region shown in Figure 2.5. The justification for modelling a relatively small area of the header is that *all* of the observed failures occured in this local region of the structure as indicated earlier in this paper.

SAP-80 provides several elaborate node generation systems which allow for the development of an extensive node mesh. In the model which was developed, three node generation schemes were utilized; Linear generation, Lagrangian generation and Quadrilateral generation. The element chosen for this model was the nine node isoparametric axisymmetric quadrilateral element. [Ref. 3: page 10] discusses the advantages of the nine node quadrilateral element over the eight node quadrilateral element for an analysis of this type. In SAP-80 this type of element is referred to as the "ASOLID" element. Figure 3.1 illustrates the local (r,s) coordinate axes as well as the Global (Y,Z) axes utilized for the axisymmetric (asolid) nine node quadrilateral element which was utilized in the model development. Despite a small increase in the computation time, the addition of the ninth node prevents some possible errors in the solution of the problem. The errors most commonly avoided are ones which arise due to the fact that some of the elements within the mesh may have significantly distorted quadrilateral shapes. The geometry of the structure contains an axis of symmetry, the center line of the superheater tube, which allows the three dimensional structure to be represented by a model which appears to be two dimensional (Y-Z Plane). The axisymmetric element type chosen rotates the structure as represented in the Y-Z Plane through 360 Degrees to form a three dimensional structure. Figure 3.2 shows the model of the header tube attachment region which was developed. The model consists of 1001 node points which form a total of 200 elements.

As shown in Figure 3.3, elements 1 through 20 were developed using the linear generation scheme. Elements 1 through 20 comprise the tube wall of the model. Figure 3.4 illustrates elements 21 through 56 which comprise the weld material of the model. Elements 21 through 56 were developed in such a manner that those elements comprised solely the weld material and no other area of the structure. This was done to allow for the possible input of separate material properties for the weld material. Figure 3.5 illustrates elements 141 through 200 which make up the header wall. Figure 3.6 illustrates elements 57 through 140 which also make up part of the header wall. Figure 3.7 illustrates the usage of the "element shrinkage" option which allows the user to uncover any possible element overlap which would produce erroneous results upon execution of the program.

In SAP-80 every node point of the structural model has six displacement components, three global translations X,Y,Z and three global rotations, RX, RY, and RZ. The directions associated with these six displacement components are known as the degrees of freedom of the node. The boundary conditions are entered by eliminating the appropriate degrees of freedom from the desired node points of the model. In the model that was developed, the right hand side of elements 188 through 200 were assumed to be fixed. To accomplish this both the Y and Z direction degrees of freedom of the appropriate node points were eliminated from the equations to be solved. The boundary between the tube and the header was considered to be a frictional surface. The node points below the weld which are on the boundary between the tube and the header were constrained together in the Y direction but the two surfaces were allowed to move with respect to one another in the Z direction.

The output from the SAP-80 code includes the following:

- Displacements
- Stresses
- Reactions

All of these results are available in either graphical or tabular form. Because of the ability to display a large amount of data in a relatively small space, the results have been presented in graphical form throughout this report. All plotted stress results in this report are in units of Ksi.

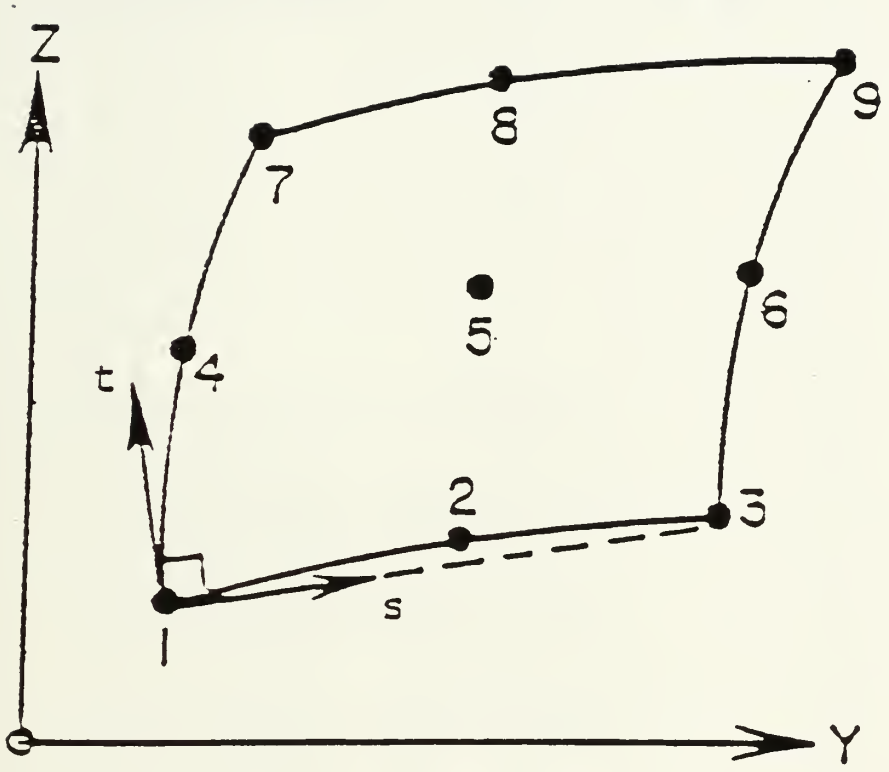


Figure 3.1 Local (s,t) and Global (Y,Z) Coordinate Axes for the "ASOLID" Element Type.

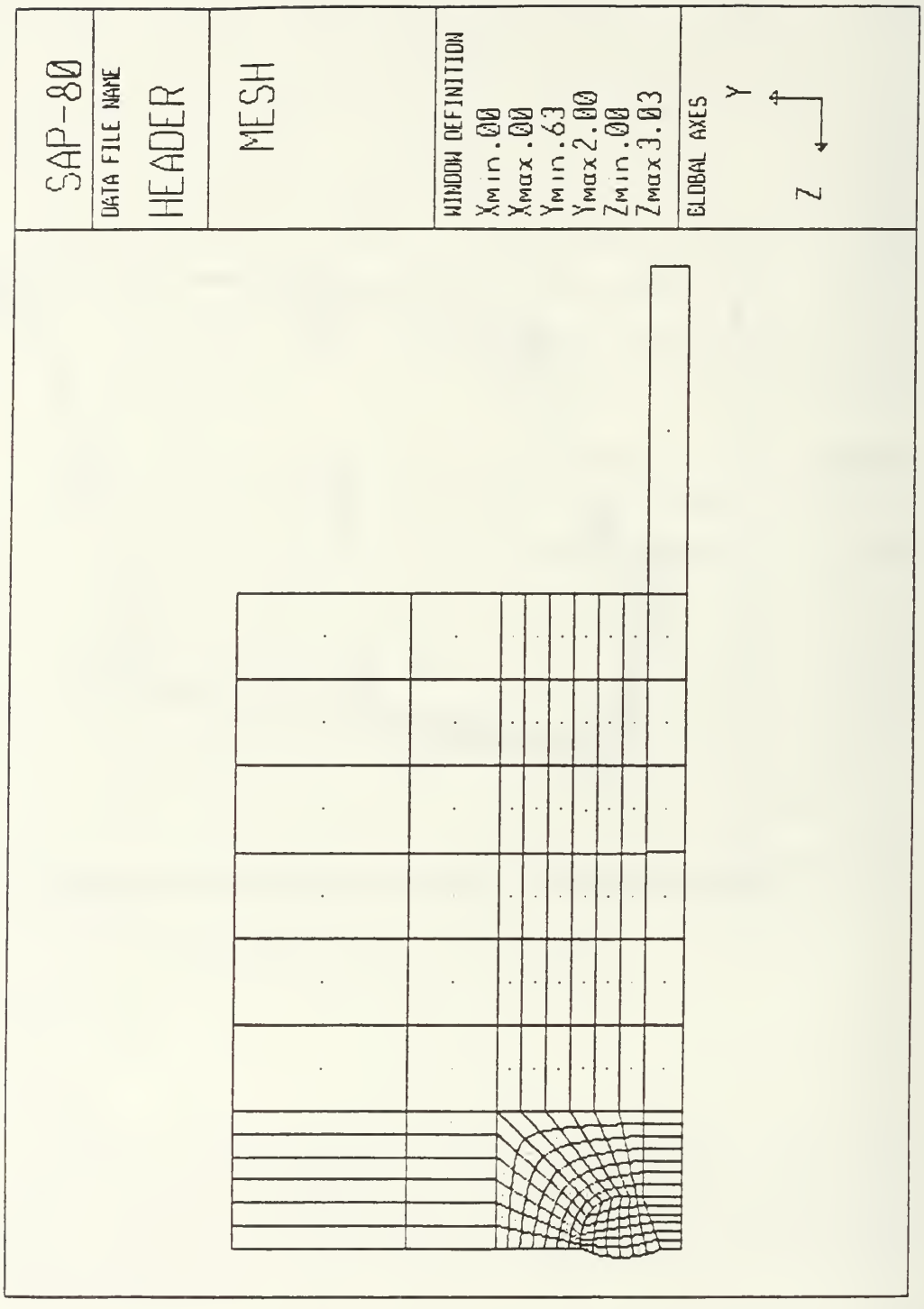


Figure 3.2 Finite Element Model of Header Tube Attachment Region.

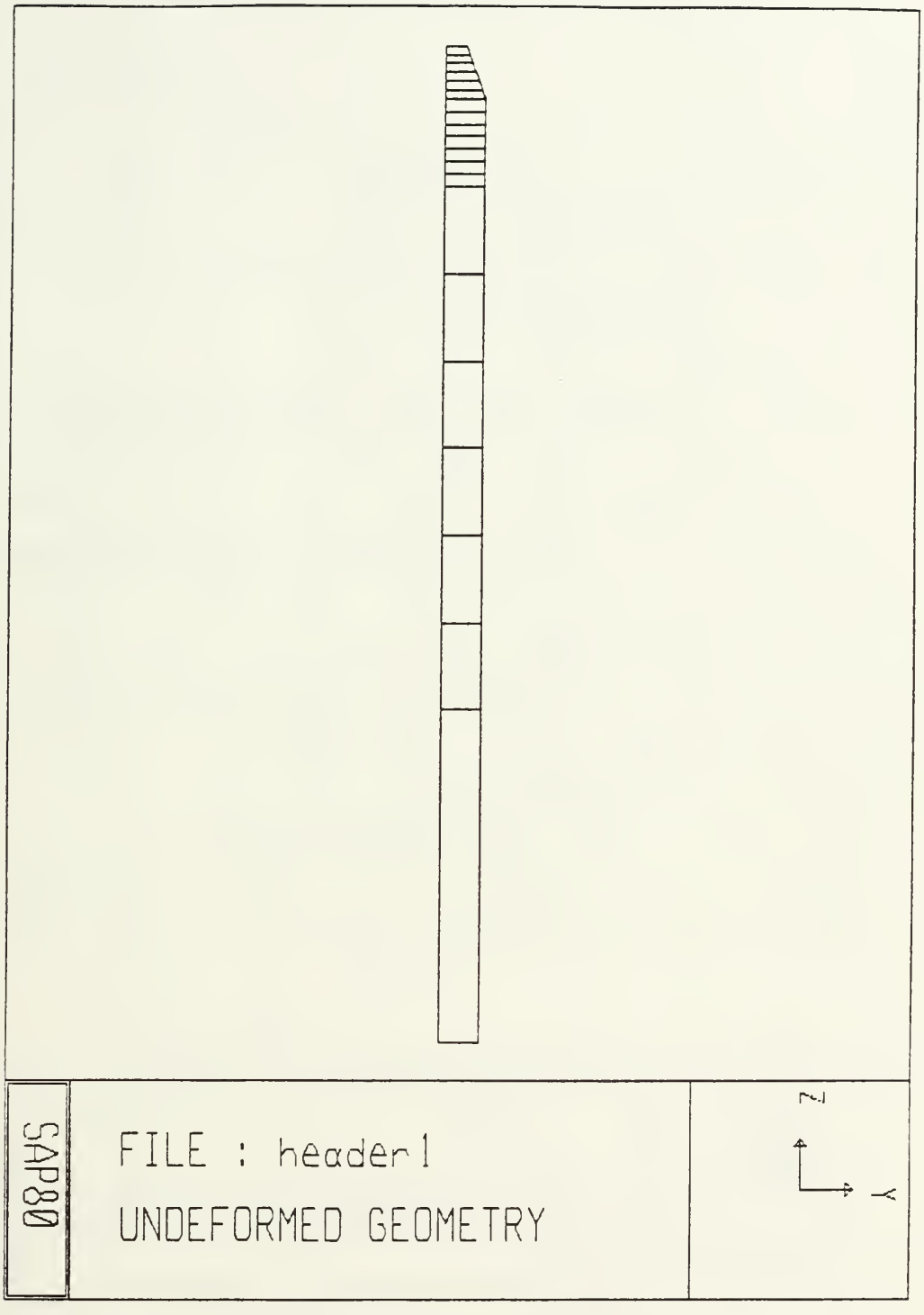


Figure 3.3 Model Elements No. 1 through 20 (Tube Wall).

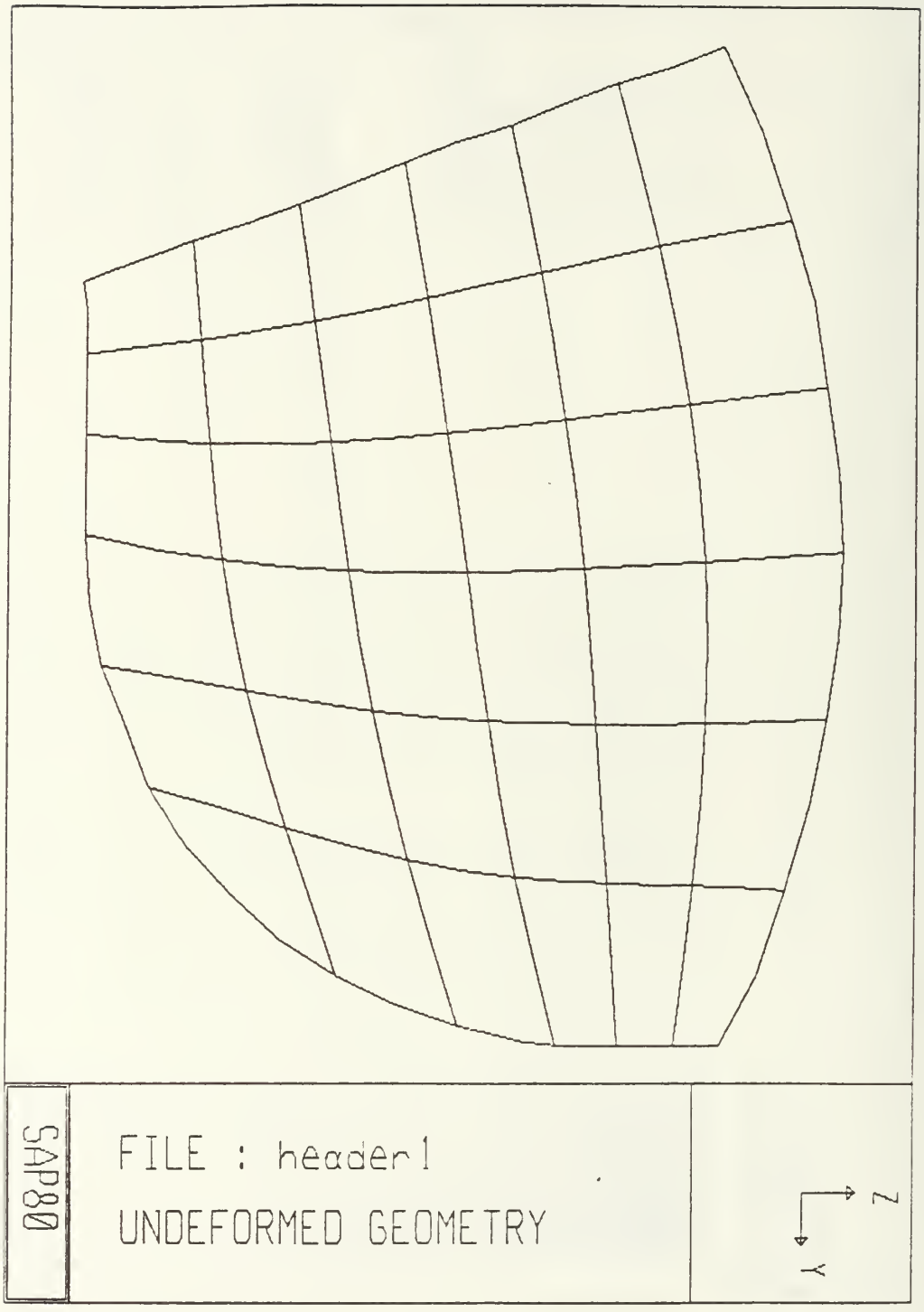


Figure 3.4 Model Elements No. 21 through 56 (Weld Material).

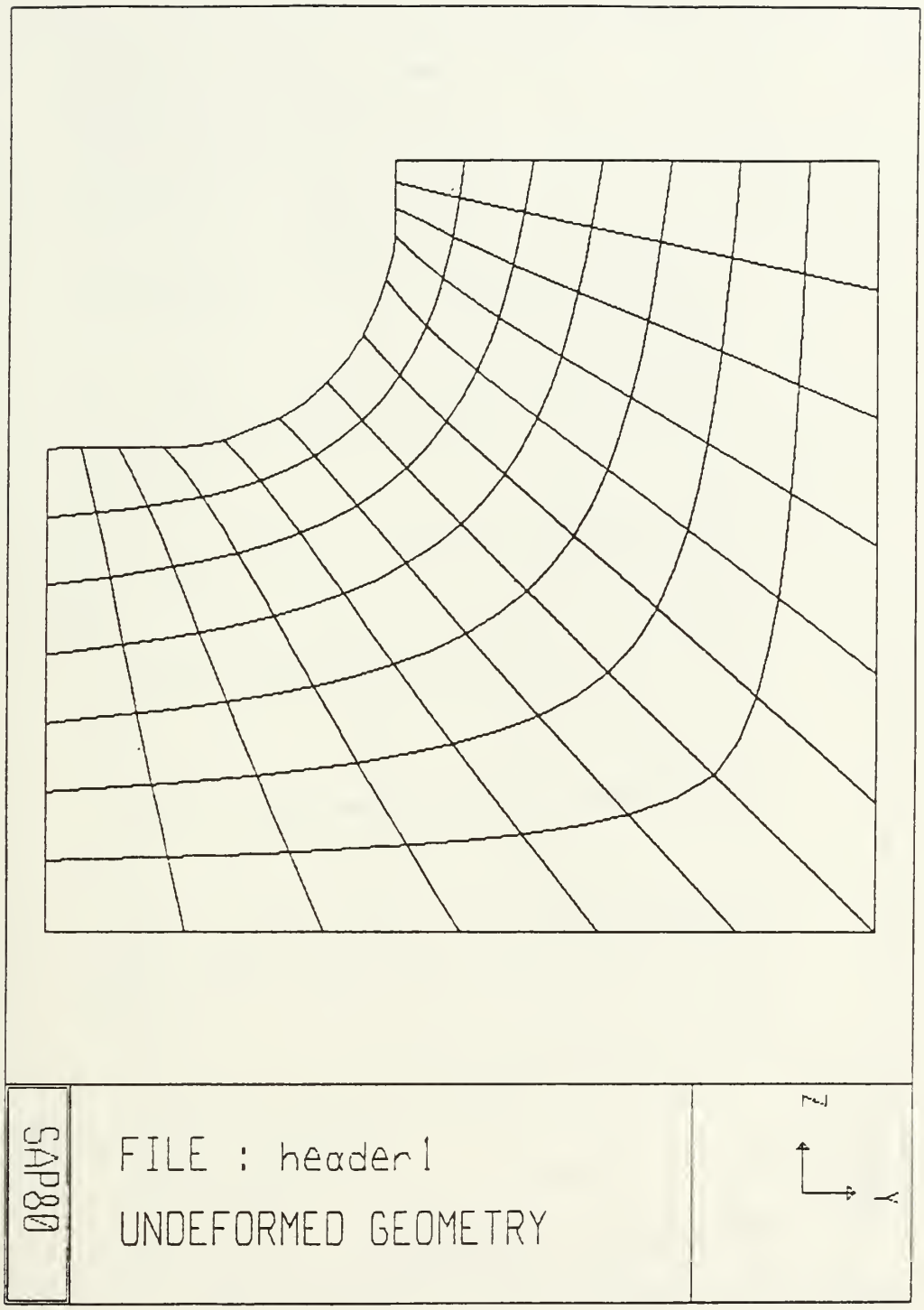


Figure 3.5 Model Elements No. 57 through 140 (Header Wall).

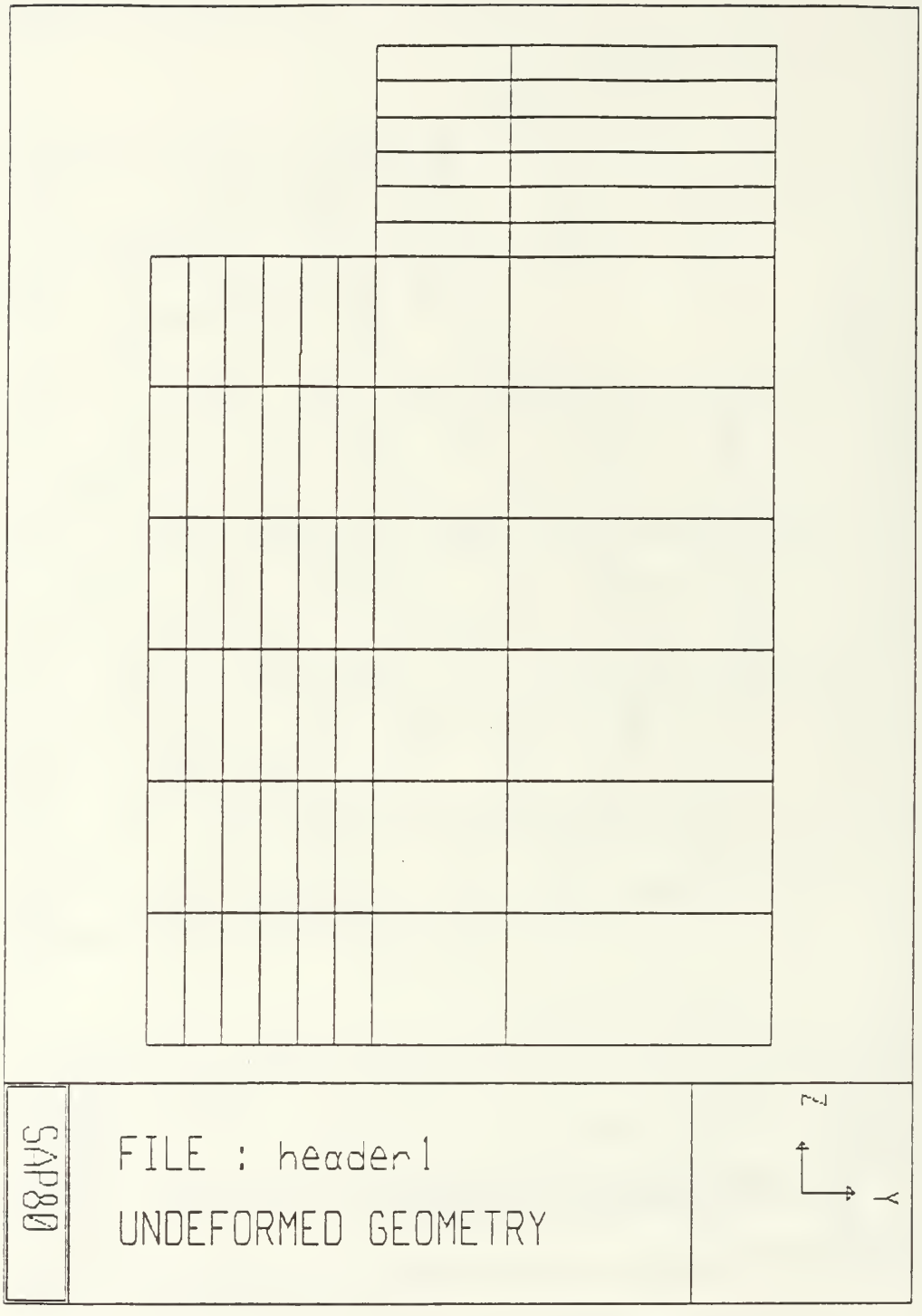


Figure 3.6 Model Elements No. 141 through 200 (Header Wall).

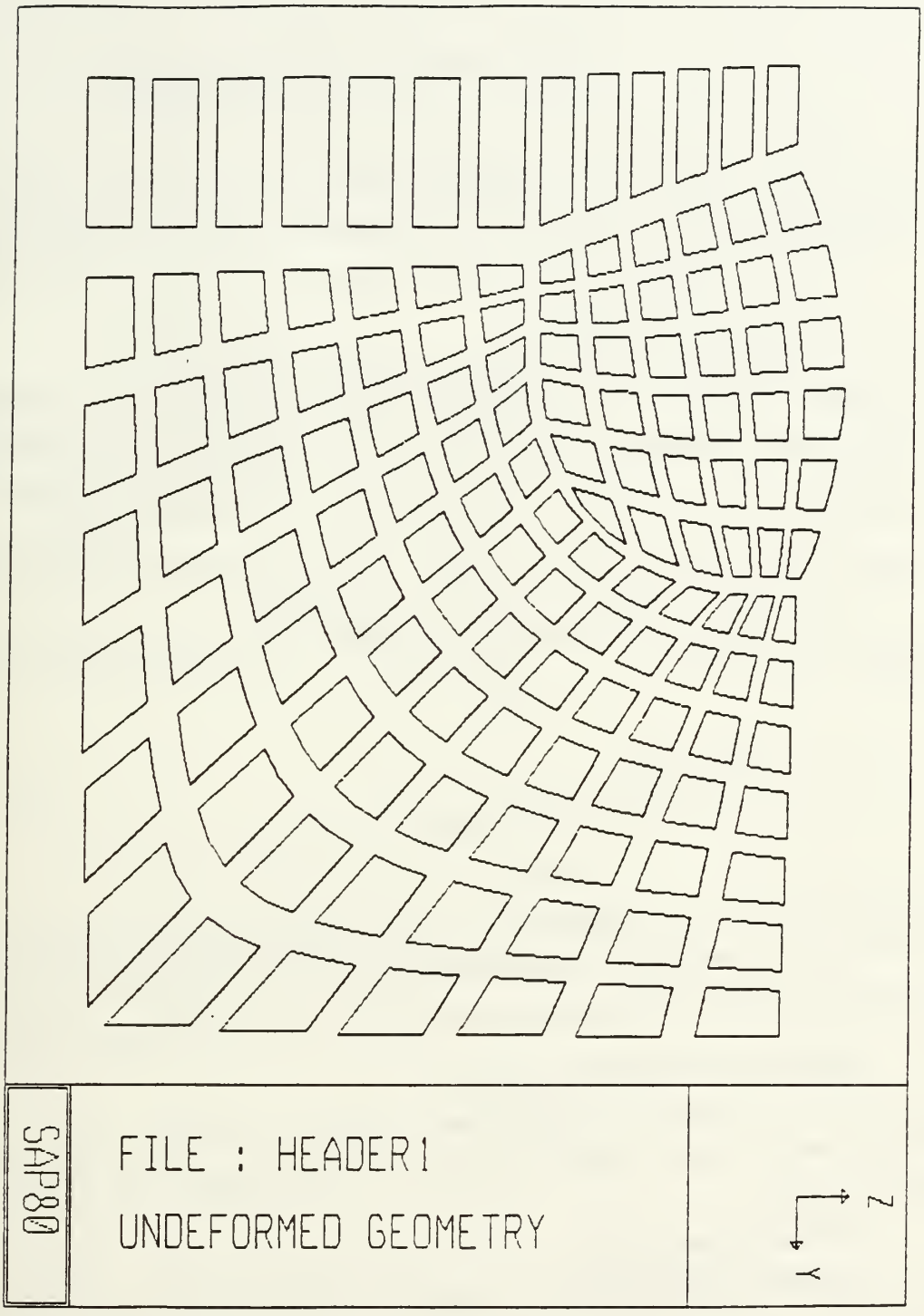


Figure 3.7 Illustration of the "Element Shrinkage" Option.

IV. SOLUTION OF THE PROBLEM

The SAP-80 code was implemented on an IBM PC AT computer at the Naval Postgraduate School. All execution including pre and post processor graphics were accomplished on the same computer.

A. MATERIAL PROPERTIES

The material used for construction of the superheater tubes as well as the header is 2.25 % Chromium 1 % Molybdenum Steel (ASTM Grade 22). The properties of concern include Young's Modulus (E), Poisson's Ratio (ν), the Coefficient of Thermal Expansion (α), the ultimate tensile strength and the yield strength. NAVSEA performed several tensile tests to obtain Yield and Ultimate tensile strength data. The results of the material tests are included as Appendix B.

The values used for the remaining properties were obtained in [Ref. 4: page 4.71], and are as listed below:

- E = 29.6 (Kpsi)
- α = 6.5 (μ Inch / Inch Degree F)
- ν = .30

It should be noted at this point that all three of these constants are actually functions of temperature and therefore they introduce some non linearities into the problem. The values mentioned above are all evaluated at approximately room temperature.

B. MODEL LOAD DEVELOPMENT

A total of three load conditions were applied to the model. These include an internal pressure load, thermal loading and a longitudinal load applied to the superheater tube.

1. Internal Pressure Load

An internal pressure load was applied to all node points which are located on the inside walls of the tube and header as indicated in Figure 4.2. During normal operation of the boiler the maximum full rating value for internal pressure is 690 Psi. As a "worst case" scenario, an internal pressure of 700 Psi was applied to the model as

described above. The results obtained for the pressure load condition alone are illustrated in Figures 4.2, 4.3, 4.4 and 4.5. In the region of interest, the maximum hoop stress obtained was 0.69 (Ksi). Figure 4.2 illustrates the hoop stresses which were calculated. Figure 4.3 and 4.4 illustrate the principal stresses which were calculated. Figure 4.5 illustrates the deformed structure with the pressure load applied. Using the "window" option all of these stresses have been plotted in the local region of the header tube attachment weld. From these results it is clear that the pressure loading condition has a minimal effect on the stress level of the superheater header structure.

2. **Longitudinal Tube Load**

The second load developed was a longitudinal load resulting from the internal pressure. If the superheater tube is assumed to be a thin walled cylindrical pressure vessel with an internal pressure, then from [Ref. 5: page 308], the longitudinal stress can be calculated as follows:

$$\sigma_l = \frac{p\,r}{2\,t} \qquad \text{(eqn 4.1)}$$

where:

- p = internal pressure = 700 (Psi)
- r = inner radius of cylinder = 0.75 (Inches)
- t = thickness of cylinder wall = 0.12 (Inches)

Using these values, the following longitudinal stress is obtained:

$$\sigma_l = 1837.5 \text{ (Psi)} \qquad \text{(eqn 4.2)}$$

This stress is then converted to a force by multiplying by the cross section area of the tube:

$$\text{Area} = \pi (r_o^2 - r_i^2) \qquad \text{(eqn 4.3)}$$

$$\text{Area} = .520 \ (\text{Inches}^2) \qquad \text{(eqn 4.4)}$$

The force F can now be calculated as:

$$F = \sigma_l \ X \ \text{Area} = 955.5 \ (\text{Lb}_f) \qquad \text{(eqn 4.5)}$$

In order to apply this force to the three dimensional model the force must be calculated per radian. This is calculated as follows:

$$F' = 955.5 \ (1/2\pi) = 152 \ (\text{Lb}_f) \qquad \text{(eqn 4.6)}$$

Now utilizing the principle of consistent loading as developed in [Ref. 6: page 164], this load was applied to nodes 85, 86, and 87 as follows:

- $F_{85} = F' \ (1/6) = 25.3 \ (\text{Lb}_f)$
- $F_{86} = F' \ (2/3) = 101.3 \ (\text{Lb}_f)$
- $F_{87} = F' \ (1/6) = 25.3 \ (\text{Lb}_f)$

This loading is illustrated in Figure 4.6

The results for the longitudinal tube load in the region of interest indicated a maximum hoop stress of 0.96 (Ksi). Figures 4.7, 4.8 and 4.9 illustrate the results

obtained for this load condition. Once again the magnitude of the stresses resulting from this load are extremely small when compared to the potential magnitude of the thermal stresses.

3. **Thermal Load**

The thermal loading of the structure in this case is probably the most important simply because of the relative magnitudes of the other stress compared to the magnitude of the thermal stresses. From the basic thermal stress equation:

$$\sigma_{th} = E \alpha \Delta T \qquad \text{(eqn 4.7)}$$

and using the values for E and α stated earlier, and a nominal Δ T of 100 Degrees F:

$$\sigma_{th} = 19.24 \text{ (Ksi)} \qquad \text{(eqn 4.8)}$$

Clearly then, the potential magnitude of the thermal stresses in this problem indicate that the development of a plausible temperature gradient for application to the model is an integral part of the stress analysis of the structure.

In order to develop a realistic temperature gradient in the structure it became apparent that a solution of the heat conduction equation was necessary. To accomplish this an analogy to the stress strain problem was developed. By making the appropriate changes to the SAP-80 code a solution to the steady state heat conduction problem was obtained. The input file for this modified problem was designated HEADERT. The input for this program was the temperature boundary conditions on the model. The data from Appendix A indicates that the maximum temperature difference between the outside and inside walls of the superheater header during operation was approximately 100 Degrees F. From this same data it was clear that the temperature variation during "flex tests" where the load is varied from 90% to 50%

and back to 90% was minimal. It became clear that the only substantial temperature gradients would exist during the start up or shut down of the boiler. The normal practice when securing the boiler is to place a "steam blanket" on the boiler as the boiler is shut down. The normal pressure of the steam used for this process is 150 (Psi). The corresponding saturation temperature for this pressure is approximately 350 Degrees F. During this process the top of the header and the surface of the superheater tube is exposed to the air inside the boiler. Using this information, boundary temperatures were assumed as illustrated in Figure 4.11. The output of the HEADERT program was the steady state temperature at each of the 1001 node points in the model. Figures 4.12 and 4.13 illustrate the temperature field which was created using the boundary conditions mentioned above. The results from the HEADERT program were substituted into the "potential" file of the HEADER program prior to solution of the equations.

Having developed a plausible temperature field for the model the program HEADER was executed. The load "combination" option of the SAP-80 code allows the user to obtain results for any selected combination of the load conditions which are included in the SAP-80 input file. The input file for HEADER contained two load conditions; the thermal loading as well as the longitudinal load applied to the superheater tube. The listing of the HEADERT and HEADER input files are included as Appendices E and F respectively.

The results for the thermal load condition, in the local region of the weld, indicated a maximum hoop stress of 19.01 (Ksi). Figures 4.14 illustrates the calculated hoop stresses in this region. Figures 4.15 and 4.16 illustrate the maximum and minimum principal stresses in the same region of the model. These results clearly show that the magnitude of the thermal stresses greatly overshadows both the internal pressure load and the longitudinal tube load.

C. ERROR CONSIDERATIONS

One of the best indicators of the accuracy of a finite element solution is to examine the results at the boundaries of adjacent elements. With the graphical results that have been presented, a feel for the accuracy can be obtained by looking closely at the stress contours that are plotted. In all of the results that have been obtained in this analysis, the stress contours exhibit extremely good continuity and there are very few places where there seems be a significant difference in calculated stresses at the boundaries of adjacent elements. Despite the fact that some of the quadrilateral

elements were quite distorted, no mathematical singularities were encountered during solution of the problem. This can most likely be attributed to the use of a sufficiently fine mesh and the nine node quadrilateral element.

Probably the largest source of error is actually introduced in the definition of the problem to be solved. In this analysis several assumptions had to made in order to arrive at an adequate problem definition. The various assumptions which were made have been discussed as they arose during the problem formulation. The assumptions made during the problem formulation are most likely the largest source of error in the solution of the problem.

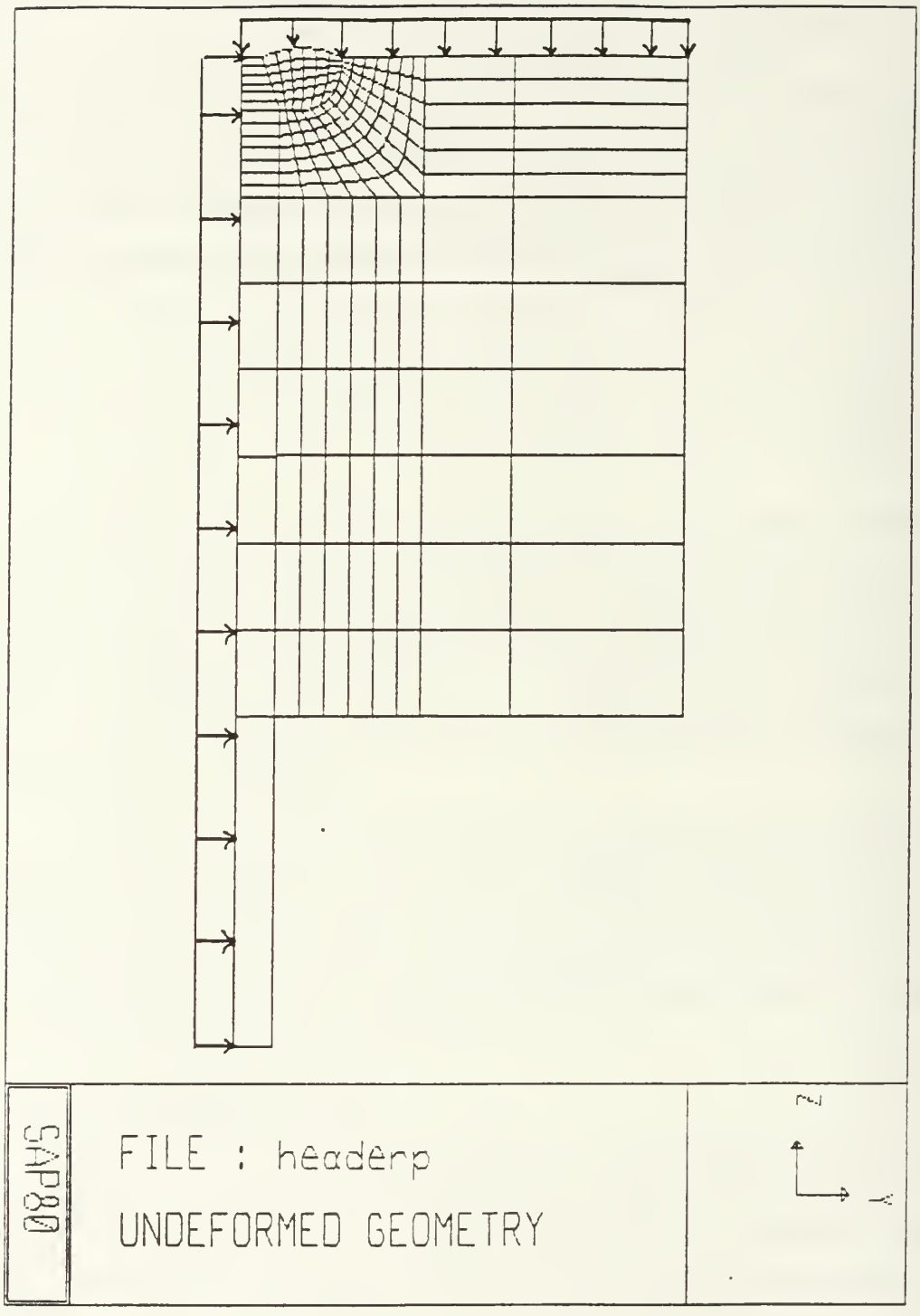


Figure 4.1 Orientation of the Internal Pressure Load.

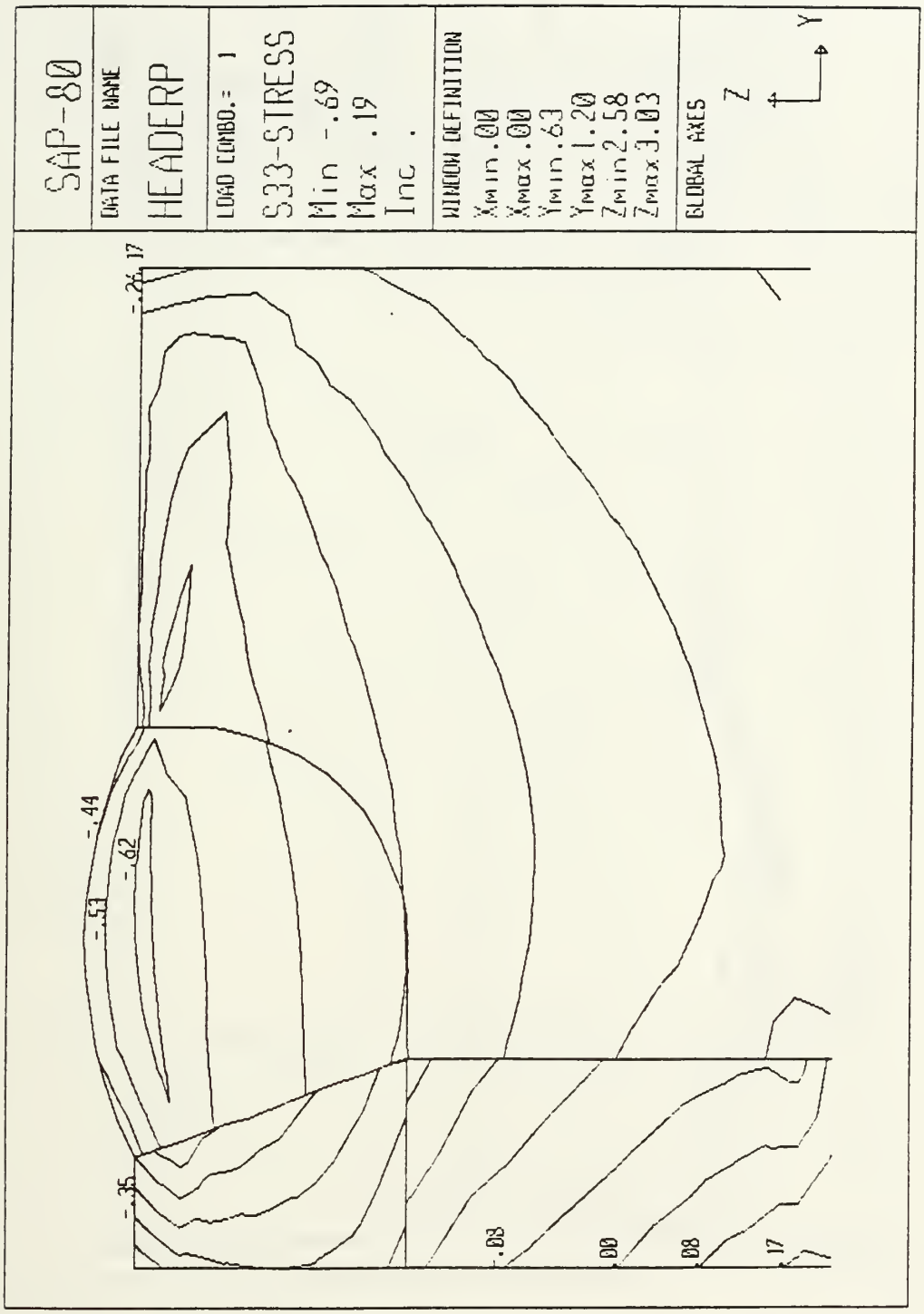


Figure 4.2 Hoop Stress for the Pressure Load Condition (Ksi).

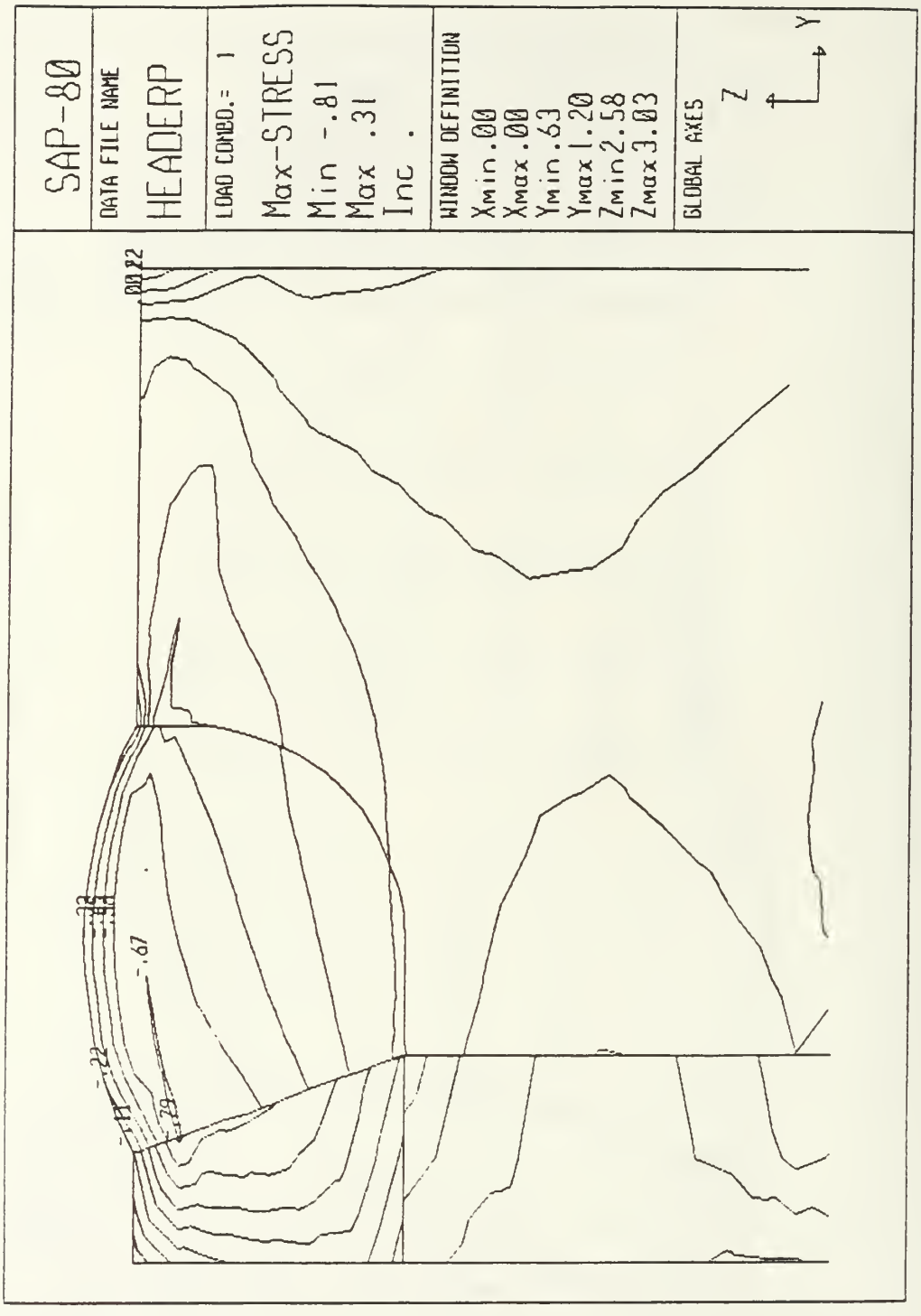


Figure 4.3 Maximum In Plane Stress for Pressure Load Condition (Ksi).

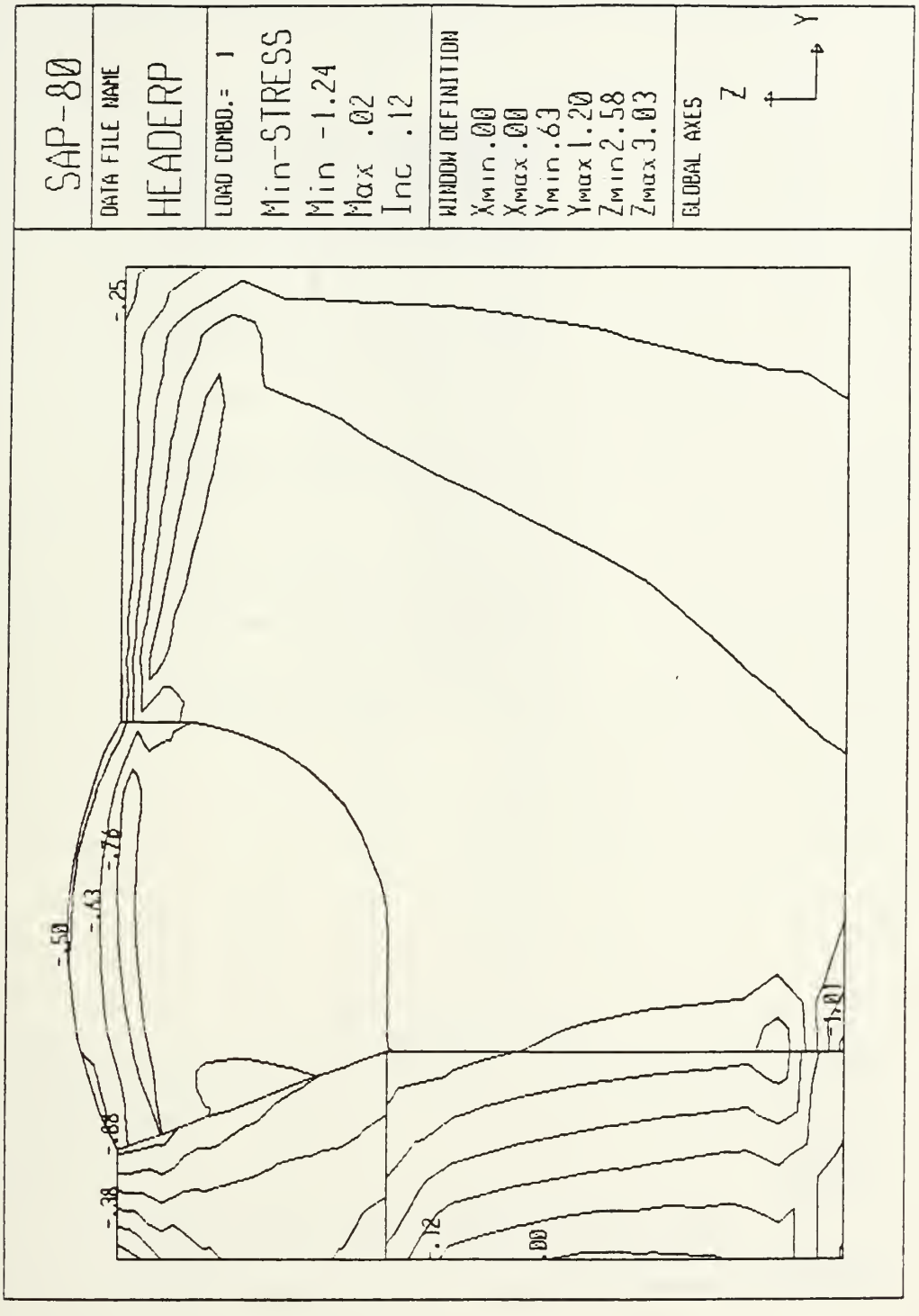


Figure 4.4 Minimum In Plane Stress for Pressure Load Condition (Ksi).

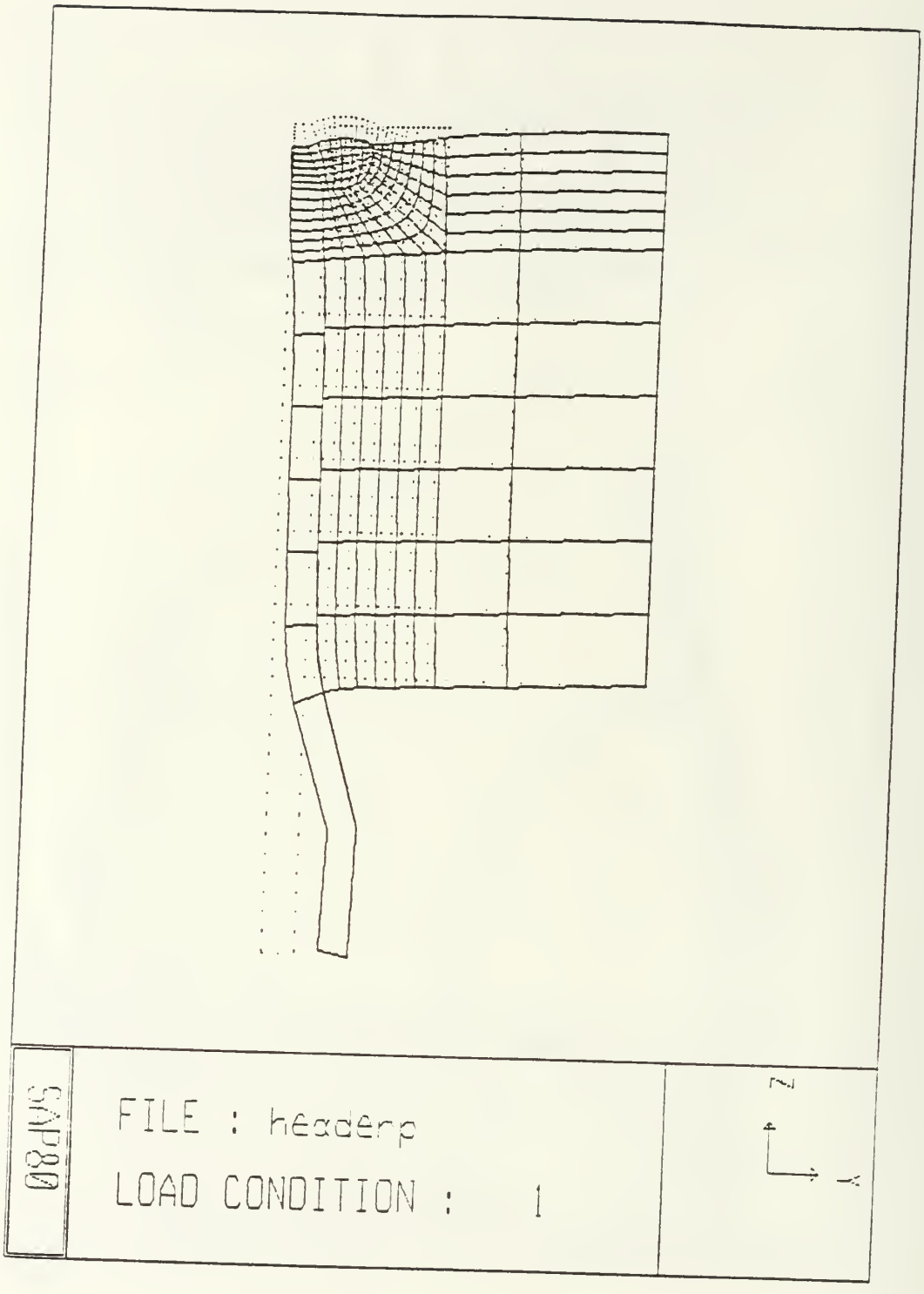


Figure 4.5 Deformed Structure for the Pressure Load Condition.

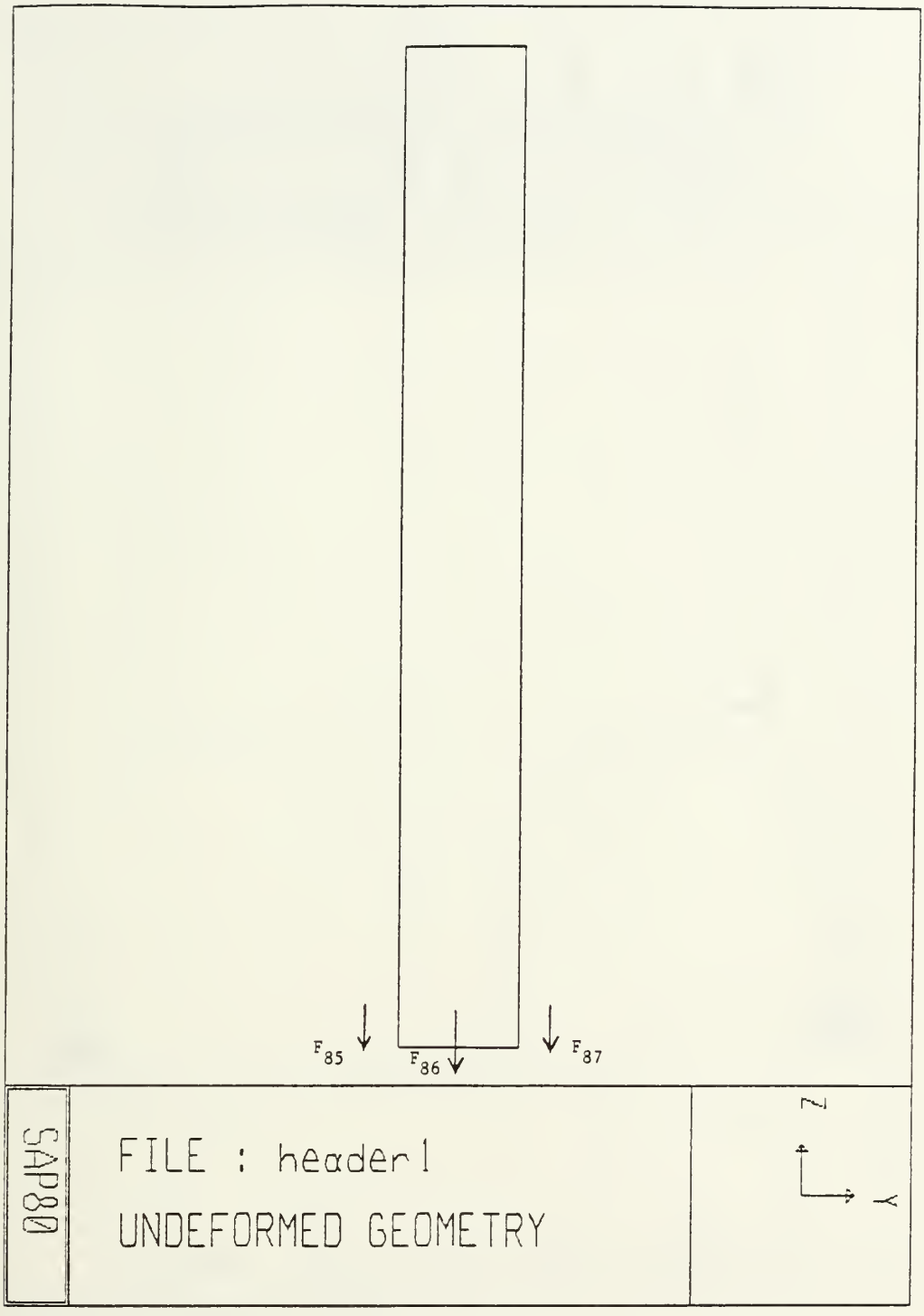


Figure 4.6 Longitudinal Loading of the Superheater Tube.

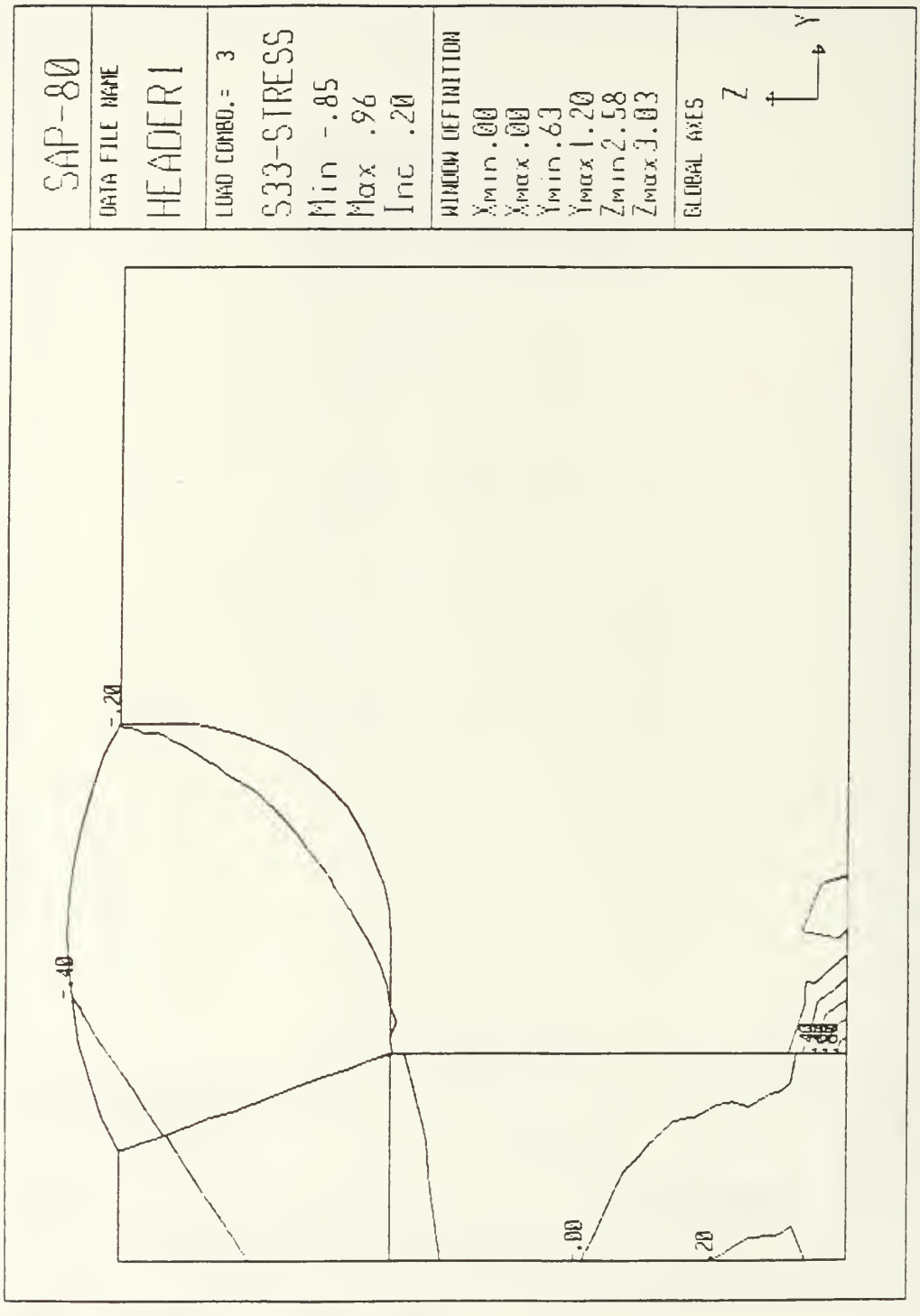


Figure 4.7 Hoop Stress for the Longitudinal Load Condition (Ksi).

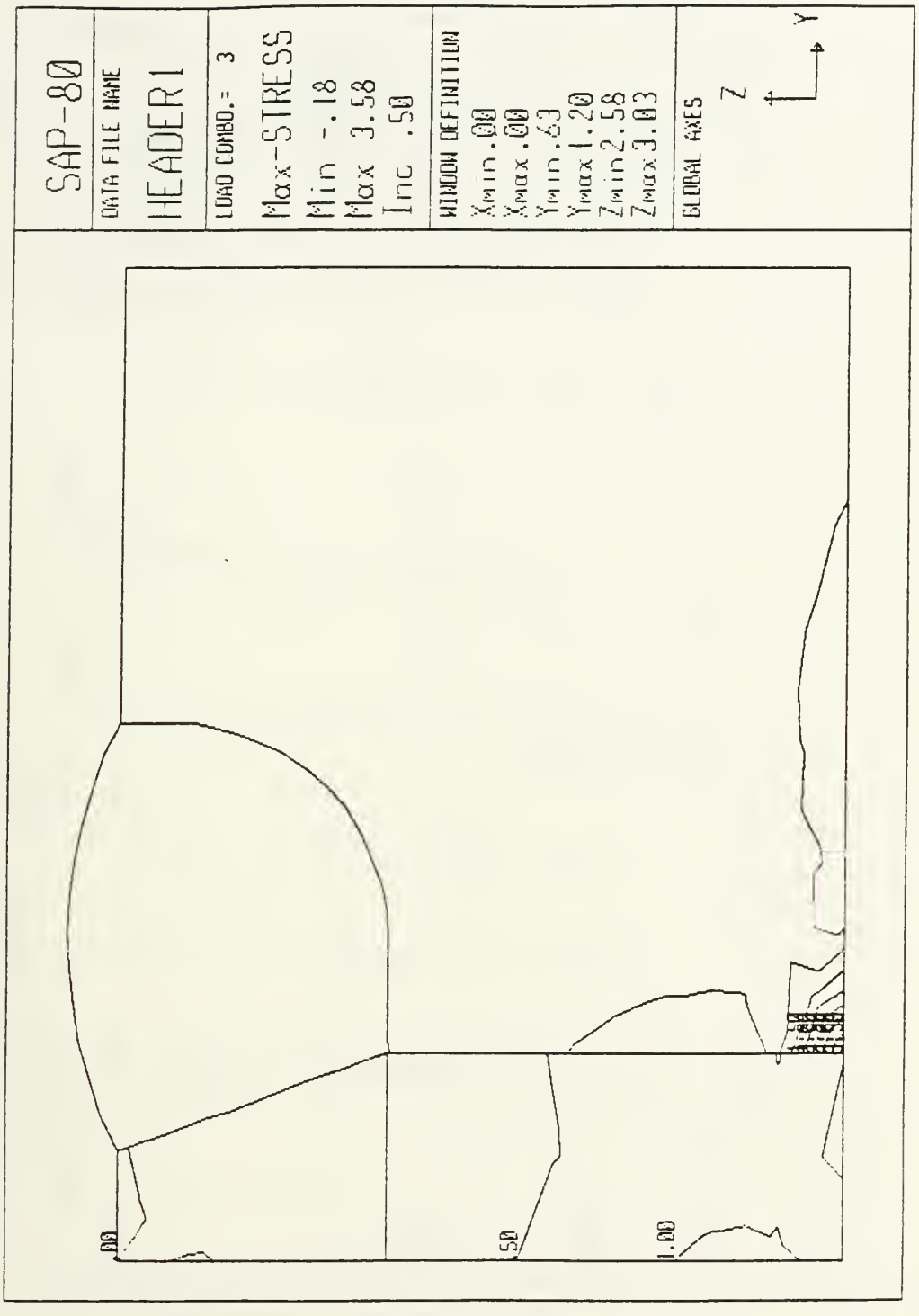


Figure 4.8 Maximum In Plane Stress for the Longitudinal Load (Ksi).

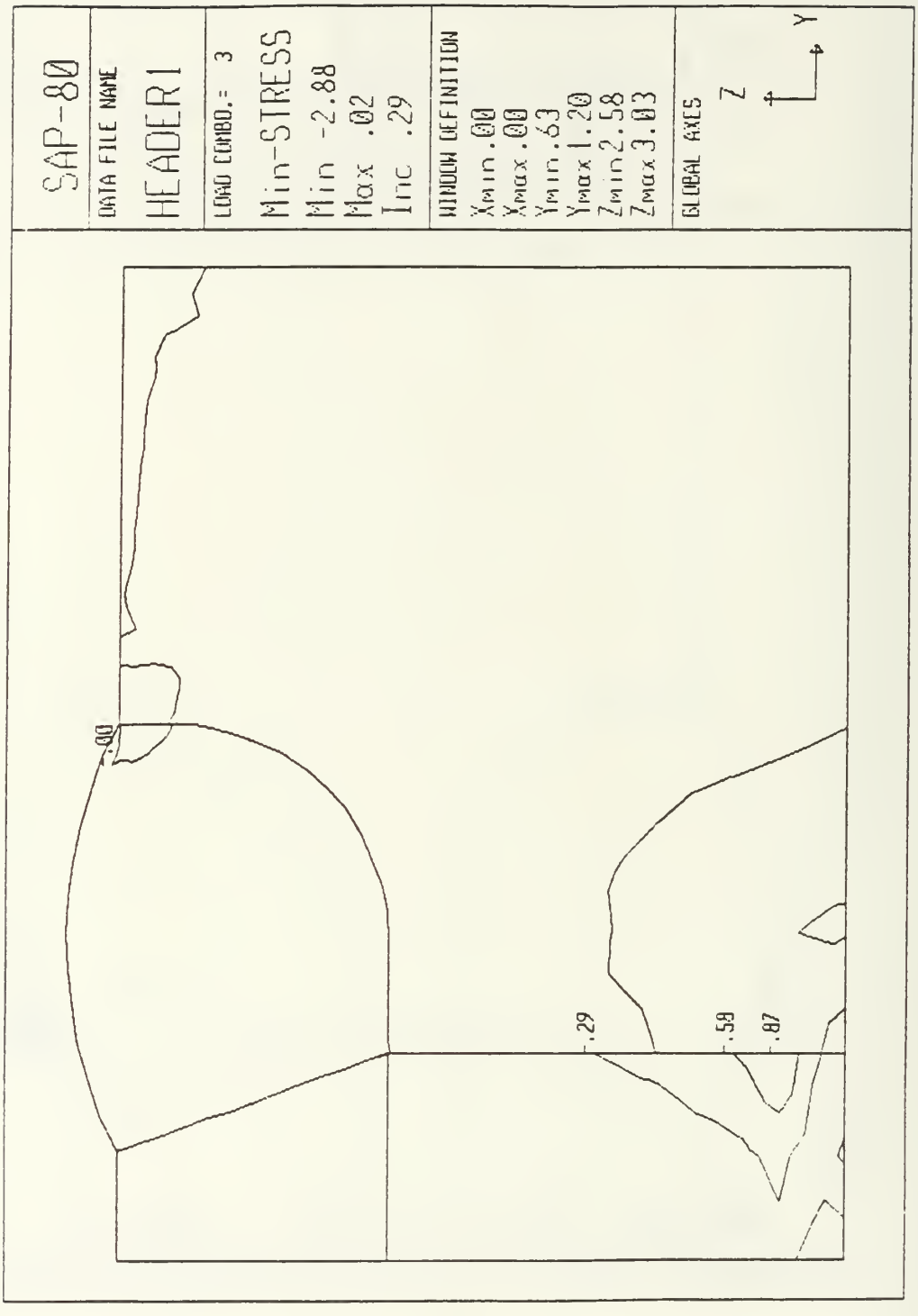


Figure 4.9 Minimum In Plane Stress for the Longitudinal Load (Ksi).

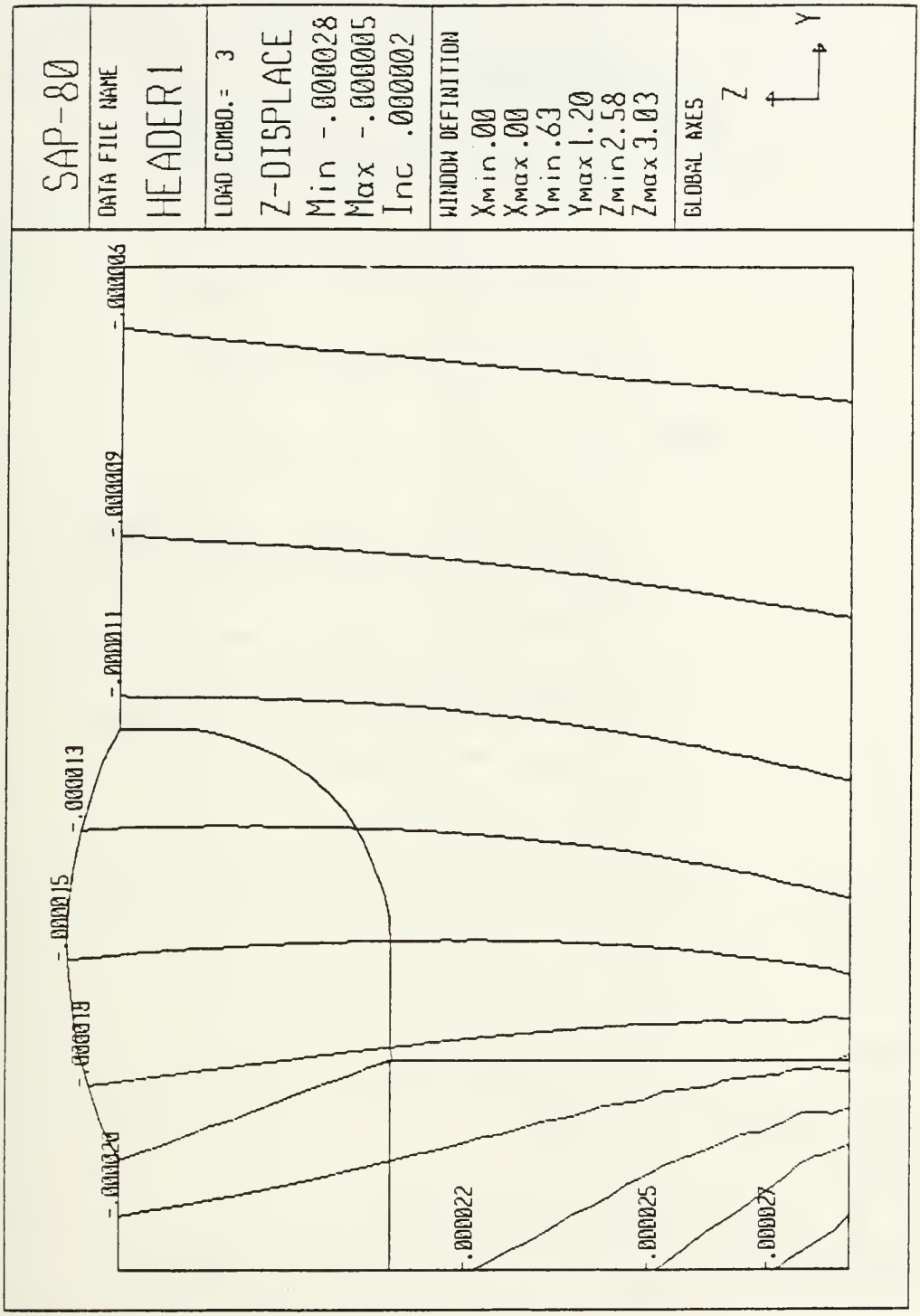


Figure 4.10 Z Displacements for Longitudinal Load Condition (Inches).

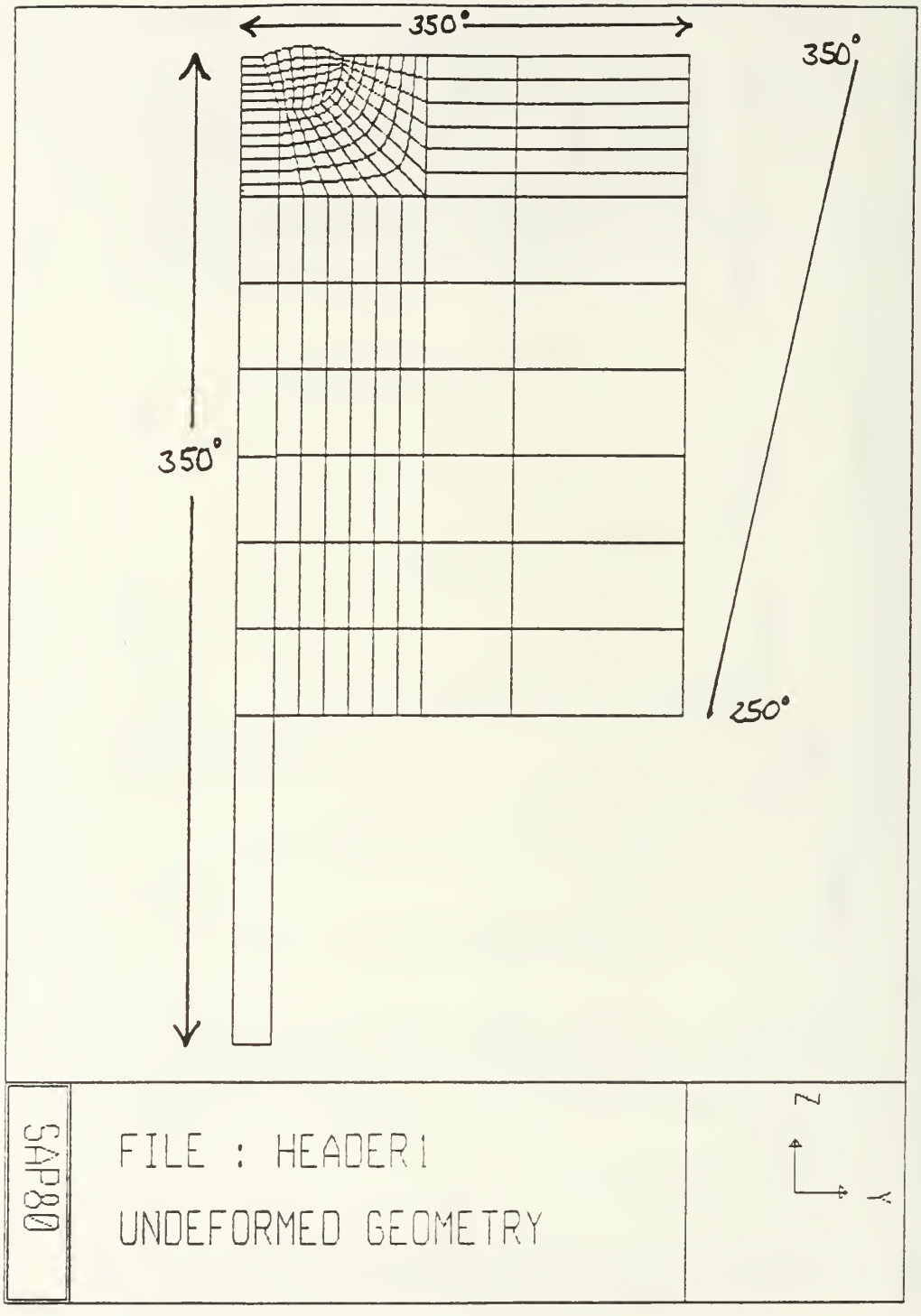


Figure 4.11 Temperature Boundary Conditions for the Model (Degrees F).

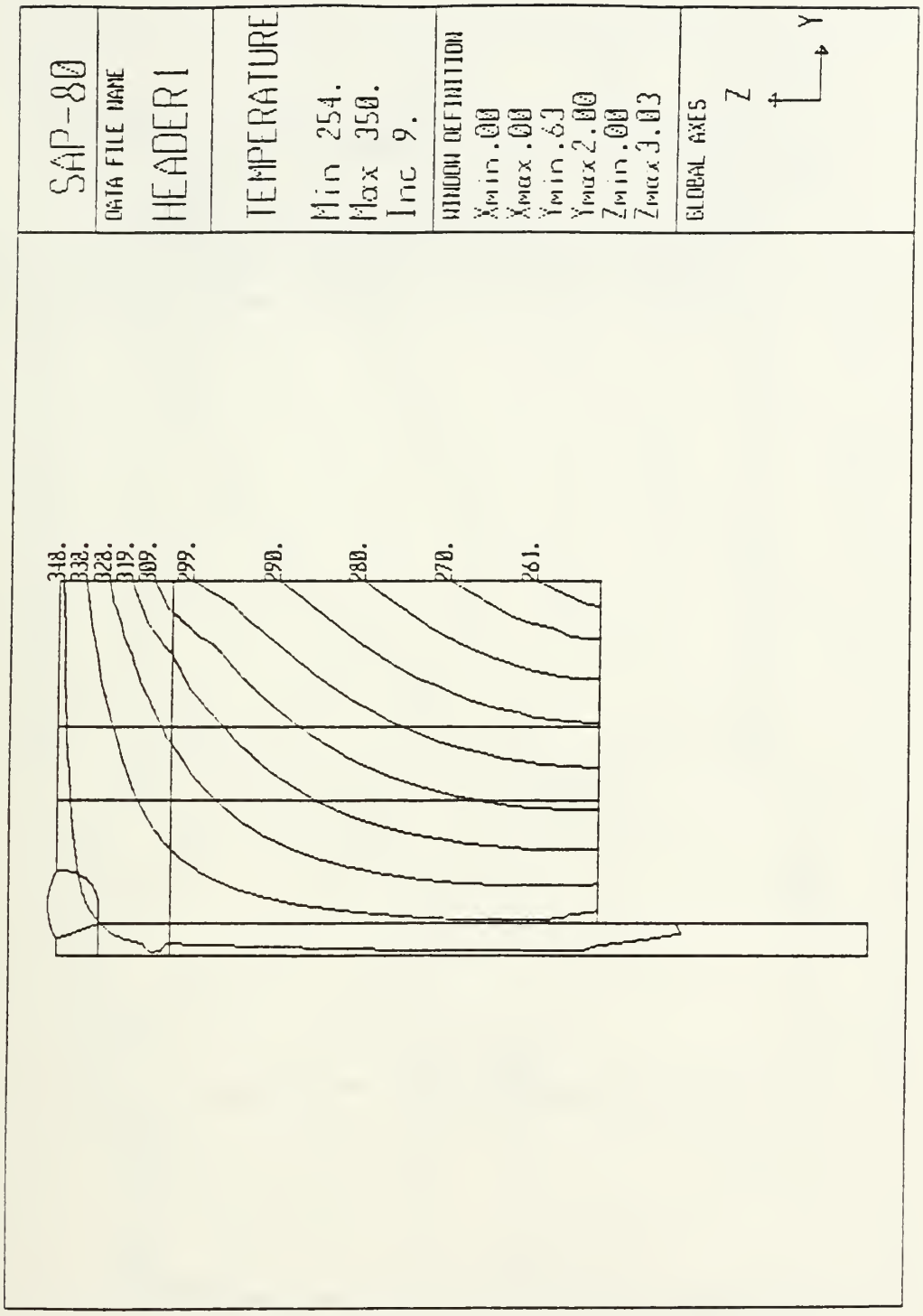


Figure 4.12 Temperature Field Developed for the Model (Degrees F).

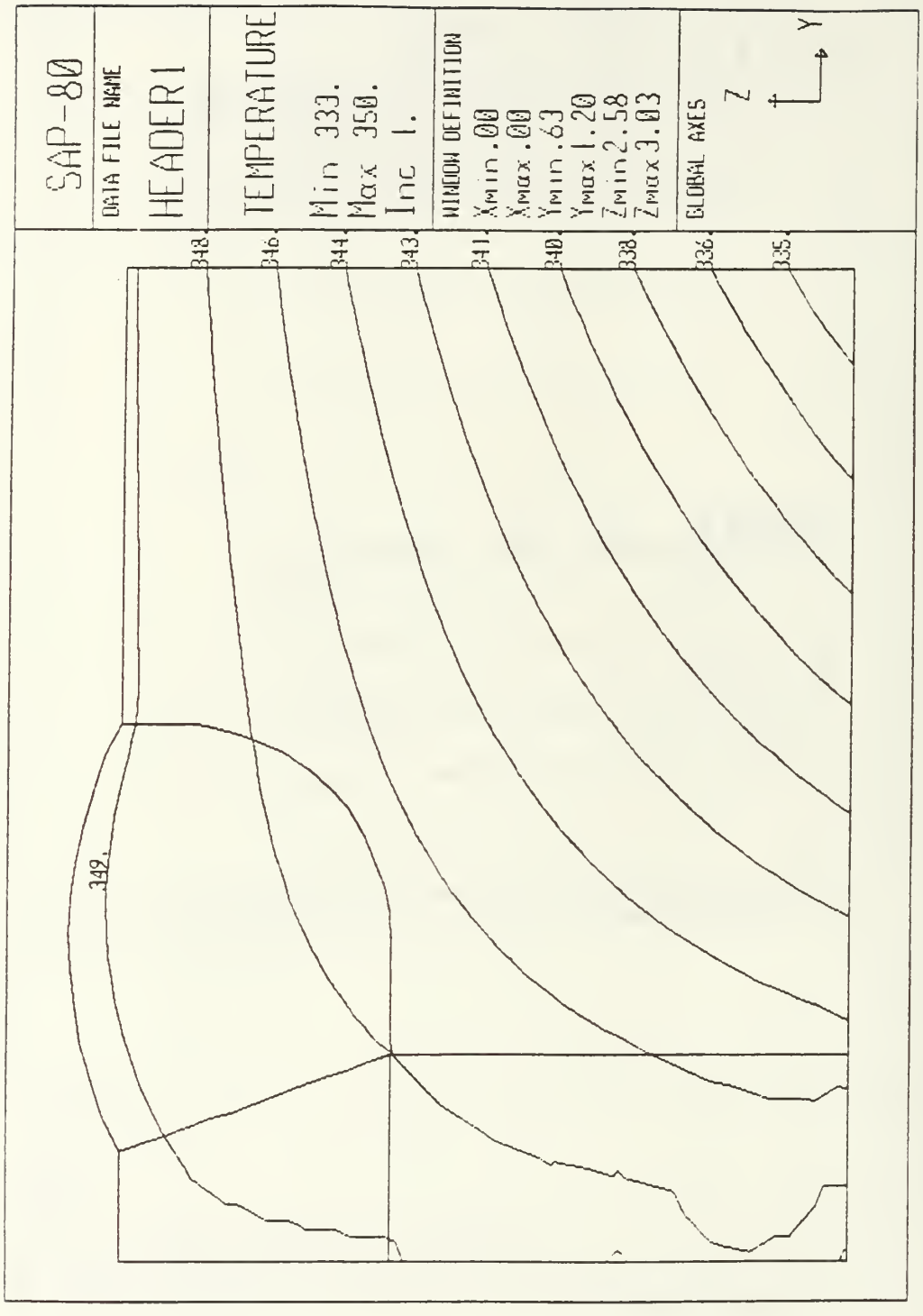


Figure 4.13 Temperature Field - Local Region of the Weld (Degrees F).

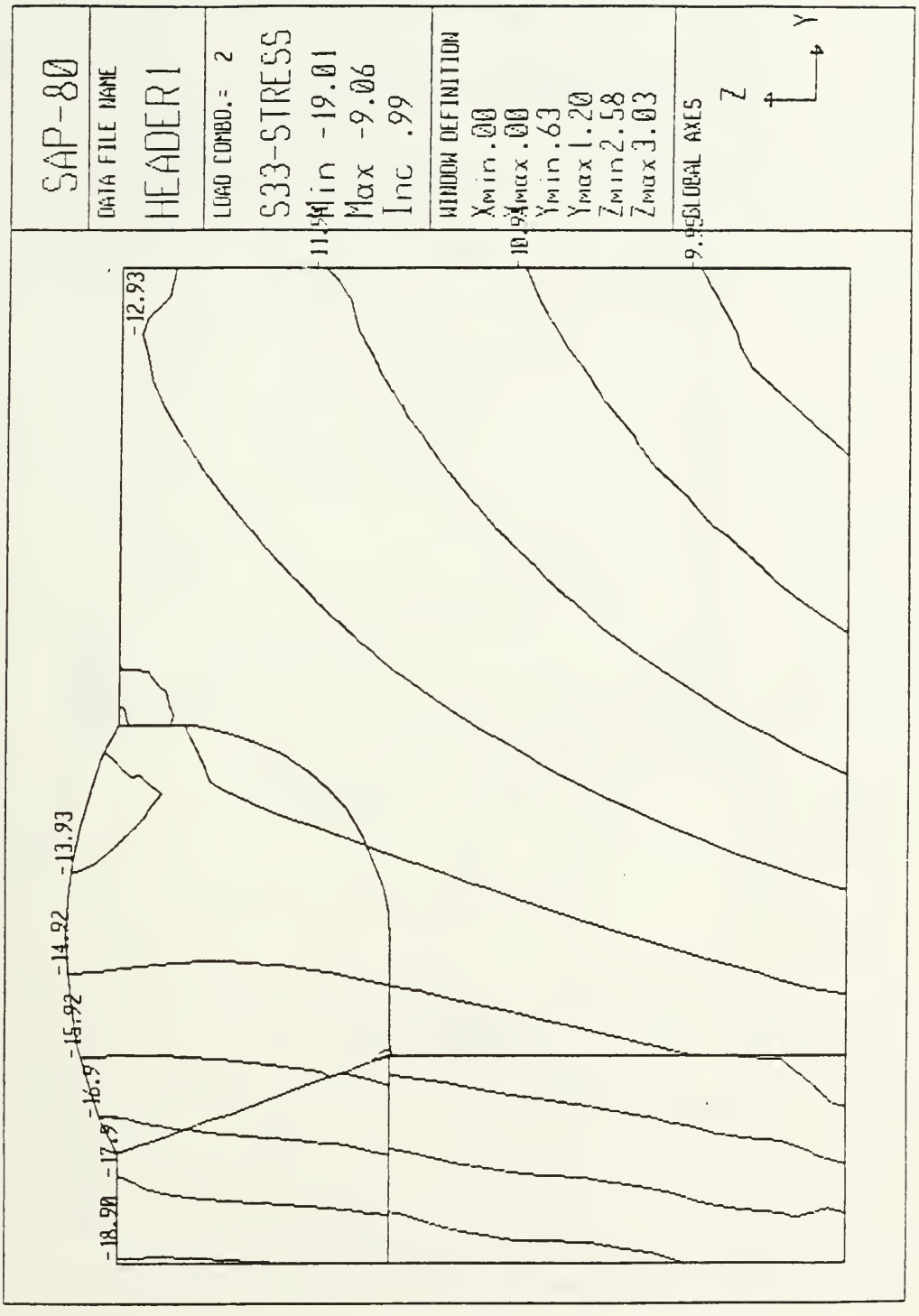


Figure 4.14 Hoop Stress for Thermal Load Condition (Ksi).

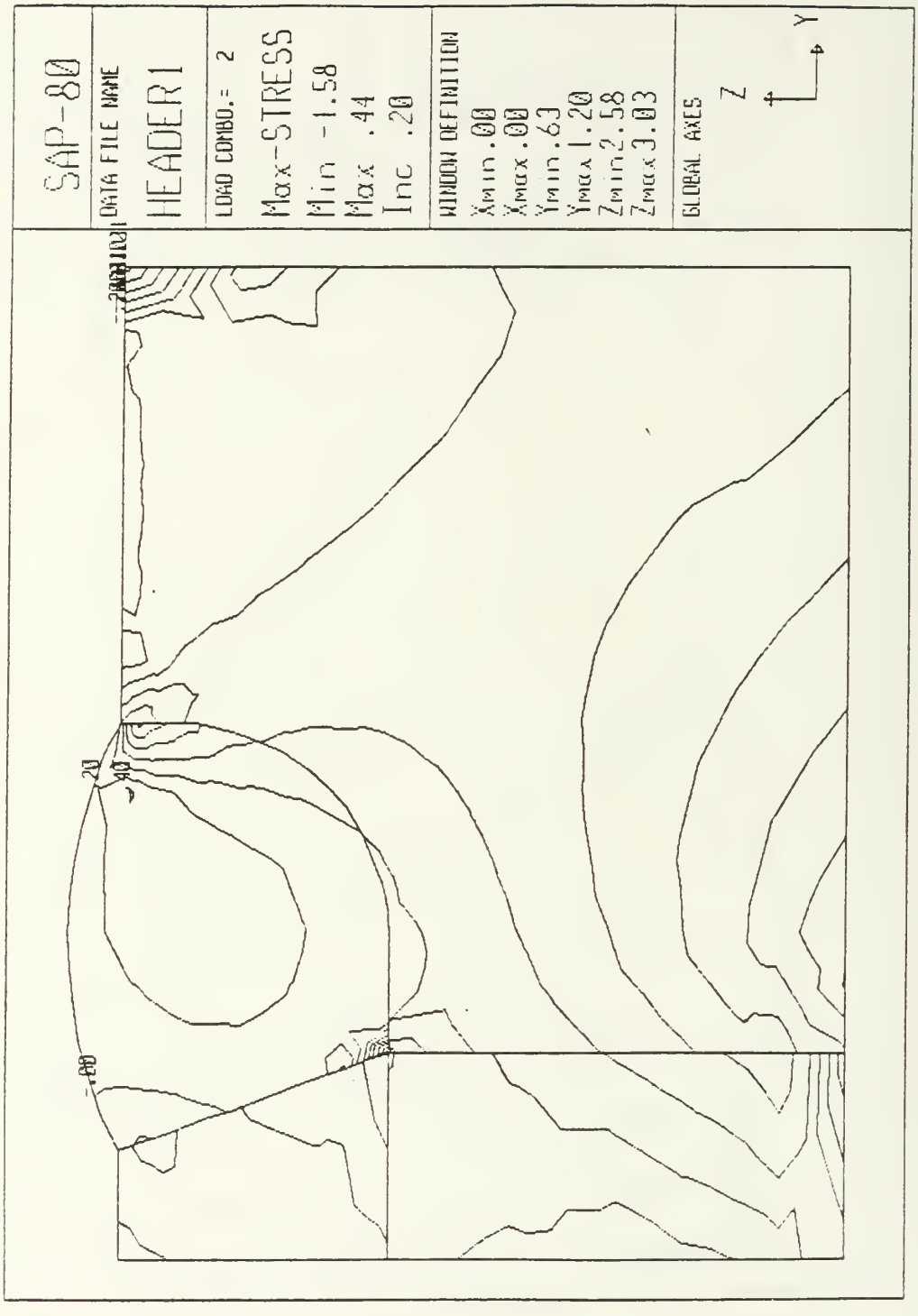


Figure 4.15 Maximum In Plane Stress for Thermal Load Condition (Ksi).

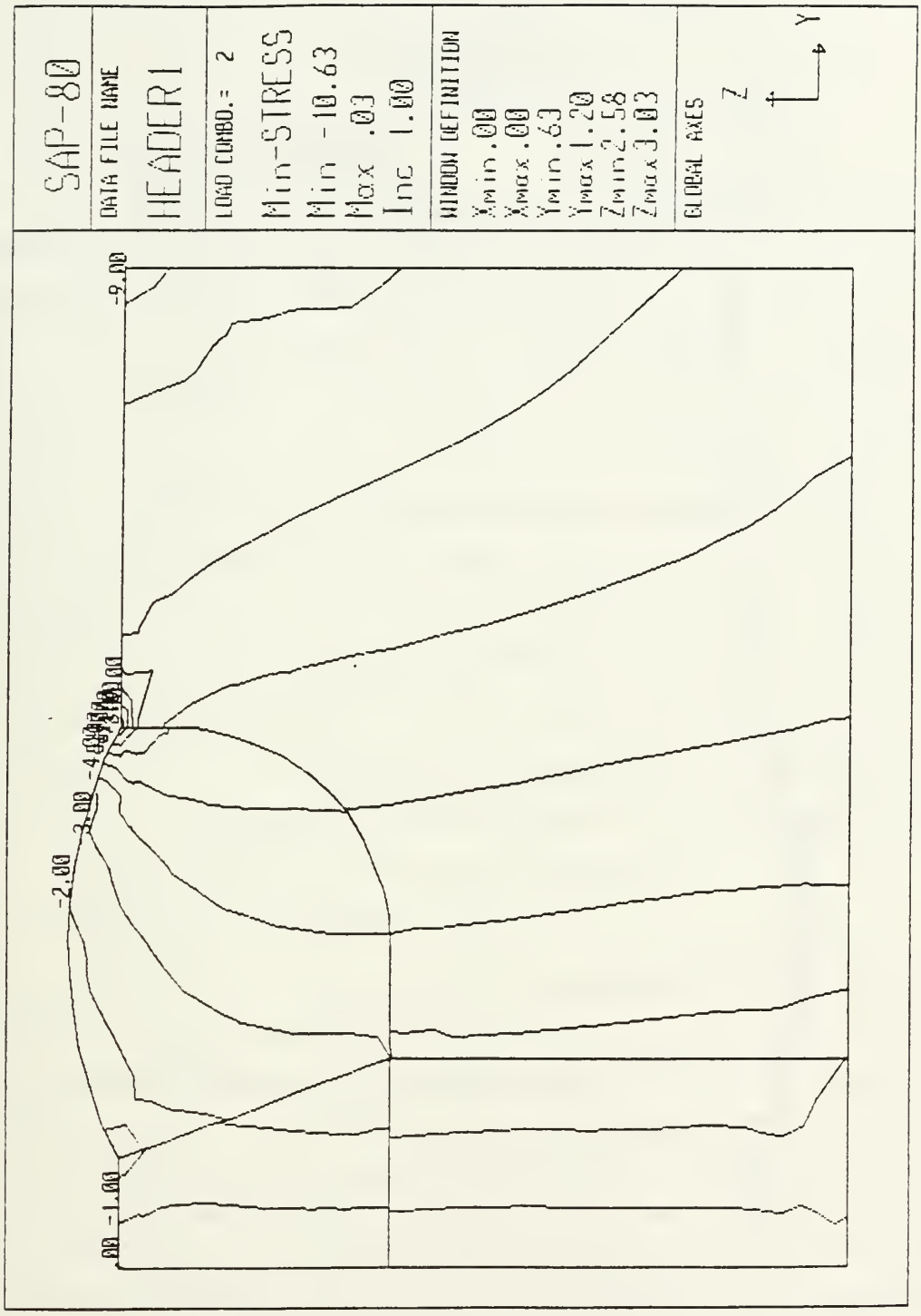


Figure 4.16 Minimum In Plane Stress for Thermal Load Condition (Ksi).

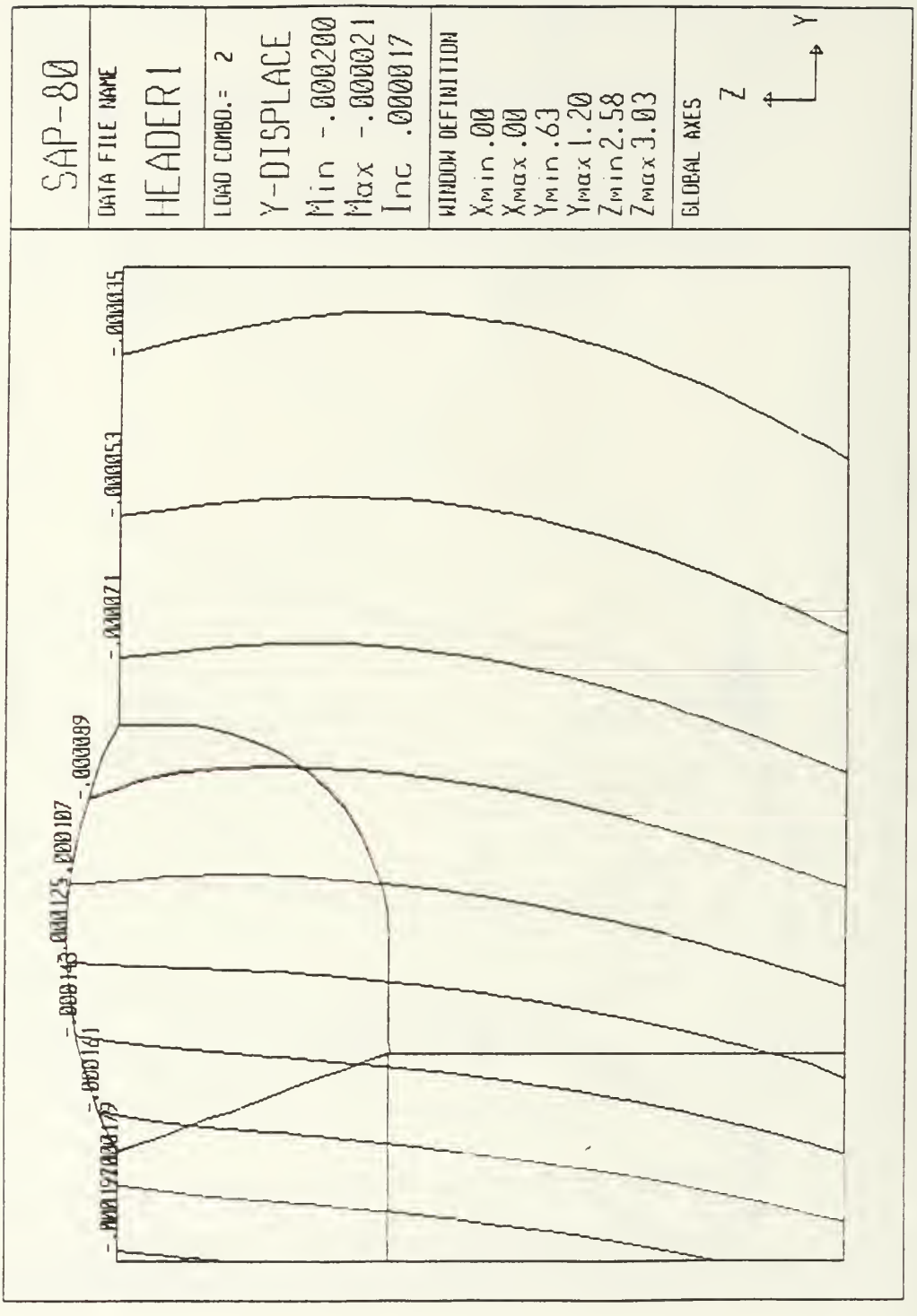


Figure 4.17 Y Displacements for Thermal Load Condition (Inches).

V. CONCLUSIONS

A. DISCUSSION OF RESULTS

As illustrated in the previous chapter, the thermal stresses are by far the most dominant stresses in this problem. The maximum calculated hoop stress of 19.01 (Ksi) does not exceed the yield strength of the material, which is approximately 35 (Ksi), as listed in Appendix B. However, if the possible effects of fatigue are considered, it is very possible that these stresses could significantly contribute to the failure of the superheater header. As indicated in Appendix E, an excerpt from the ASME boiler code, for an operating temperature of 400 Degrees F the maximum allowable stress is 15.0 (Ksi). Appendix F indicates that during a five year operating cycle there would be approximately 300 boiler shutdowns. Approximately 50% of these shutdowns would employ the use of a steam blanket as described earlier. The rest of the shutdowns would be from operating pressure down to ambient pressure. These shutdowns not utilizing a steam blanket would lead to even larger thermal gradients in the header. Although the data in Appendix F is for the CV-60 class of ship, the operating cycle should be similar to the operating cycle of the LHA-1 class. Using this criteria, the results of the stress analysis would definitely indicate that a possible failure condition exists. Some other pertinent considerations are included below.

1. Superheater Header Design

The U.S. Navy employs a similar header cross section in six classes of ships. The only class which has experienced such a large number of failures is the LHA-1 class. The other applications which use a similar cross section differ in one major area. The other applications of this header utilize a "sectionalized" design. In this design instead of having one inlet/outlet header and one intermediate header which run the entire width of the boiler, the header is broken down into four smaller headers, with each of the smaller headers being approximately one fourth the width of the boiler. For the LHA-1 class the steam inlet temperature is approximately 500 Degrees F and the outlet temperature is approximately 850 Degrees F during normal operation. Therefore the superheater header is subjected to a temperature difference of approximately 350 Degrees F from the inlet side to the outlet side. In the case of the "sectionalized" headers, the temperature difference from the inlet to the outlet of each

section is in most cases less than 100 Degrees F. Since it has been demonstrated that the thermal stresses and in particular the temperature gradients which produce them, are the driving force for the stresses experienced in the header, it would seem that the LHA-1 class definitely has the potential for larger thermal stresses to be developed. Also adding to the problem is the fact that the LHA-1 class header has a mass which is approximately four times that of each of the smaller sections. From the consideration of the heat transfer problem, this would lead to a much longer time for the header to reach equilibrium and therefore the header would be subjected to these larger thermal gradients for a longer period of time. From a structural point of view, the sectionalized headers provide more flexibility and thus tend to reduce stresses.

2. **Effects of Creep**

Although this study has not considered the effects of high temperature creep on the structure, these effects are certainly important in this problem. If the boiler is operated at an elevated temperature for an extended period of time, it is possible that through the creep relaxation process that the header could actually experience extremely small stresses or possibly a zero stress condition during elevated temperature operation. However, after this extended period of elevated temperature operation it would be possible for a "stress reversal" to take place when the boiler is secured. If for example, the header was in compression during elevated temperature operation, upon shut down of the boiler it might be possible for the header to actually go into a state of tension. If it is also considered that this process would occur each time the boiler was secured, this process could lead to a fatigue condition in the header.

3. **Effects of Vibration**

Despite the fact that the effects of vibration have not been studied in this report it is certainly possible that a frequency analysis of the structure would yield some significant information. Since the V2M boiler is the largest propulsion boiler employed by the U.S. Navy, the superheater tubes are subjected to an extremely large volume of air flowing through and around the superheater structure. It would seem that the potential for some significant stresses to be produced due to vibration exists. The possiblity of a resonance situation is one which certainly would justify further investigation of the transient response of this structure.

B. OPPORTUNITIES FOR FURTHER RESEARCH

The model which has been developed in this thesis provides a basis for further studies to be made of the structure in question. With this basic model, the effects of

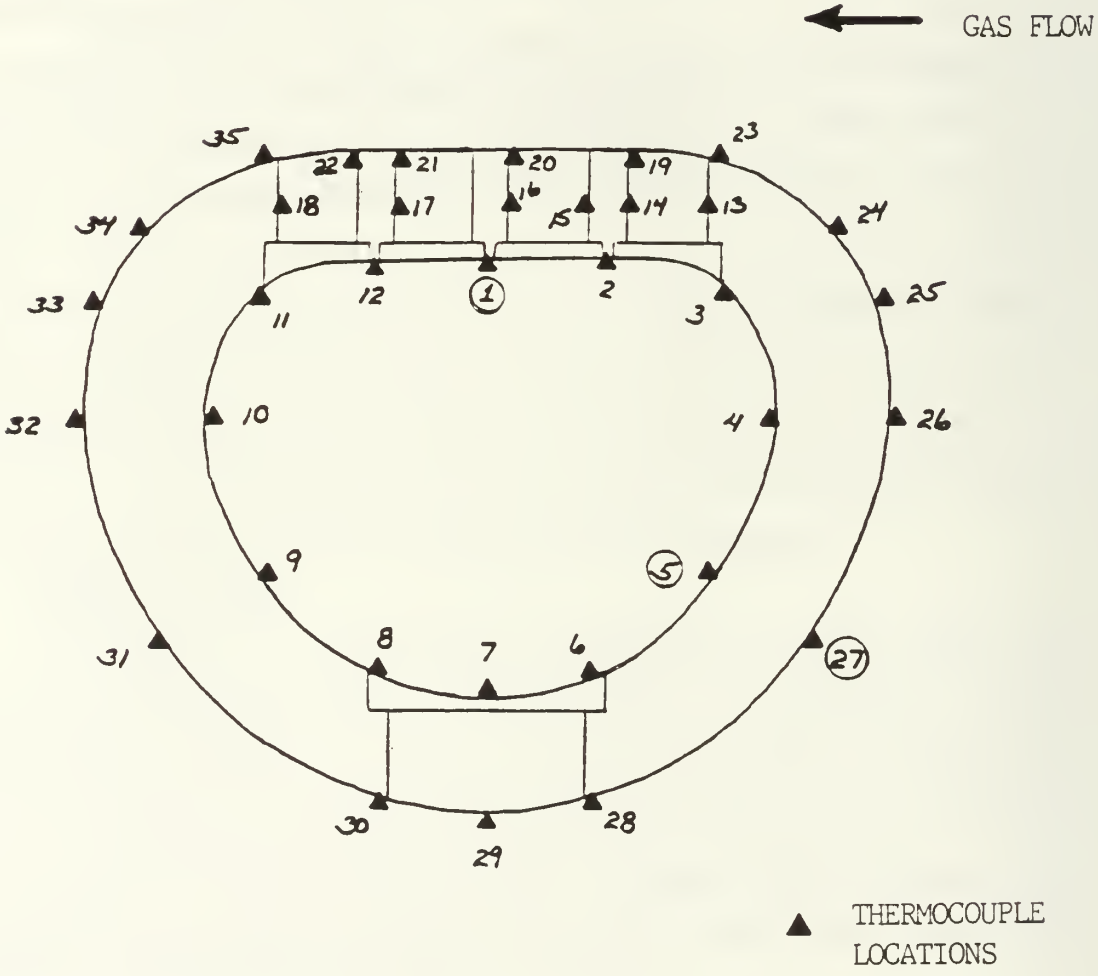
numerous load conditions, boundary conditions and temperature fields can be studied. Some possible avenues for further investigation are listed below:

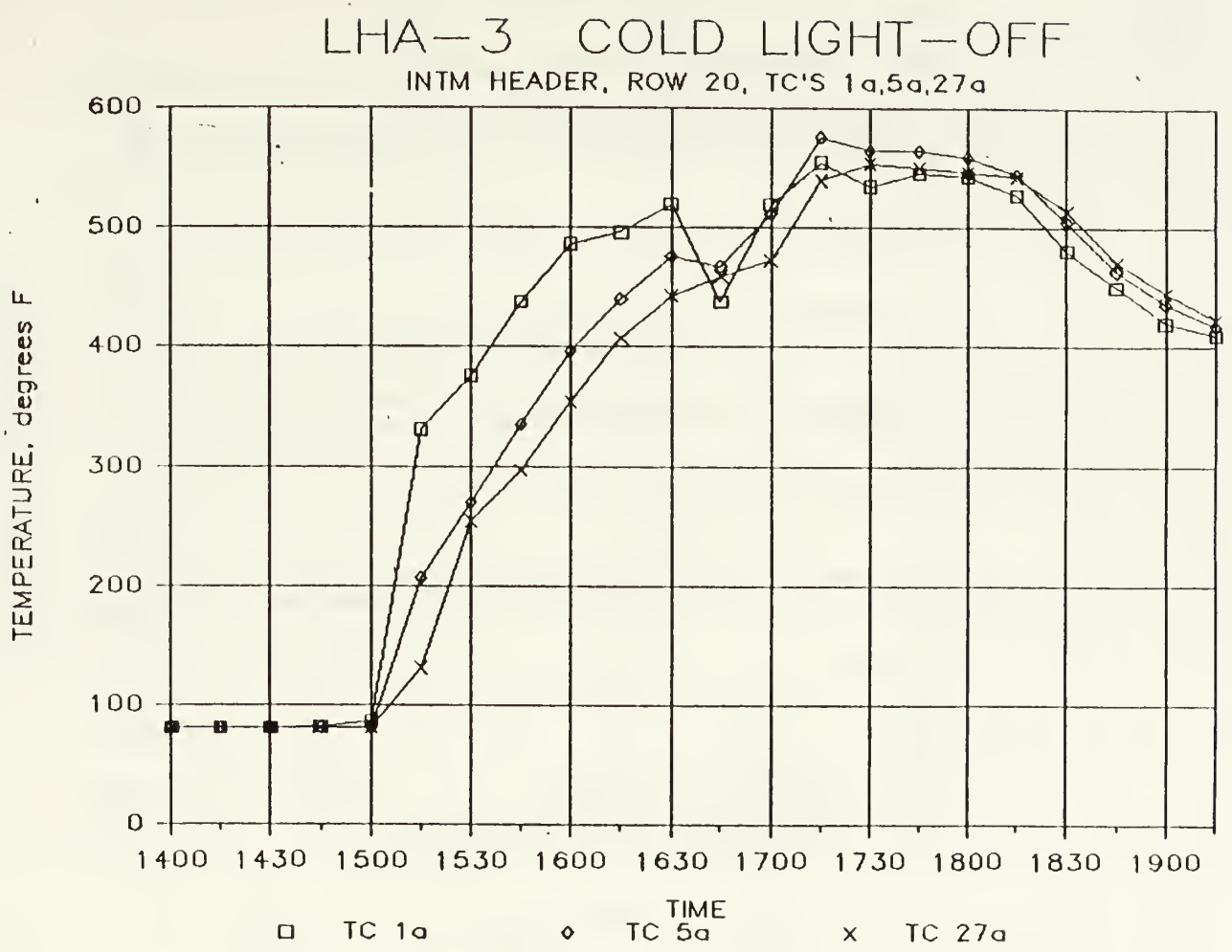
- Obtain more detailed experimental temperature data in the weld region
- More detailed study of the heat conduction problem
- Inclusion of temperature dependent material properties
- Inclusion of distinct material properties for the weld material
- Consideration of high temperature "creep" effects on the structure
- Transient response of the structure
- Further investigation of appropriate boundary conditions

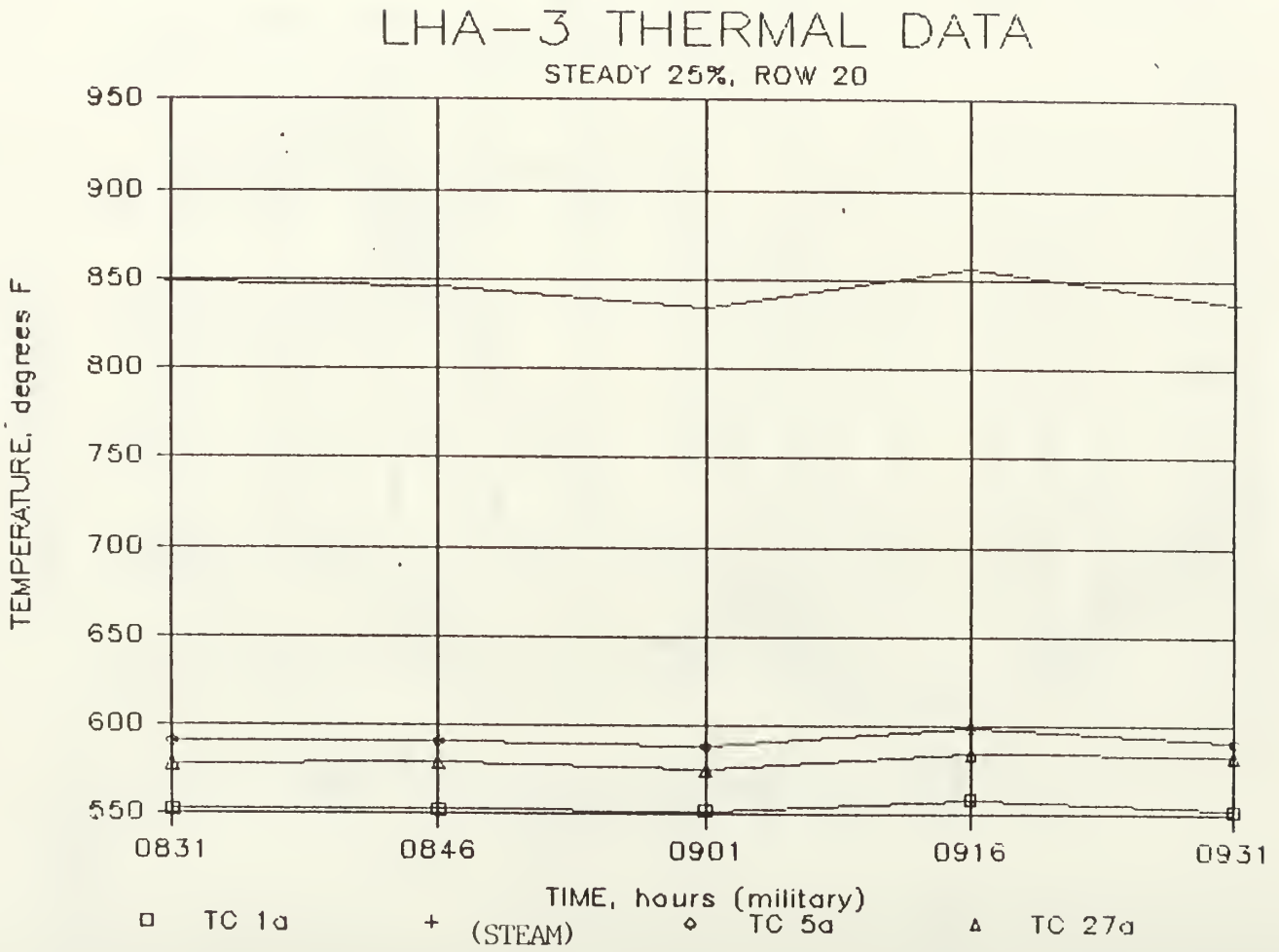
Due to the complexity of this problem, it is not likely that one report could include all of the possible areas to be investigated. This report has attempted to develop a basic model of the superheater header tube attachment region and to identify and investigate the significant factors affecting the stress level and possible failure of the structure. It is hoped that follow-on studies will be made to further investigate the cause or causes of the numerous failures which have taken place.

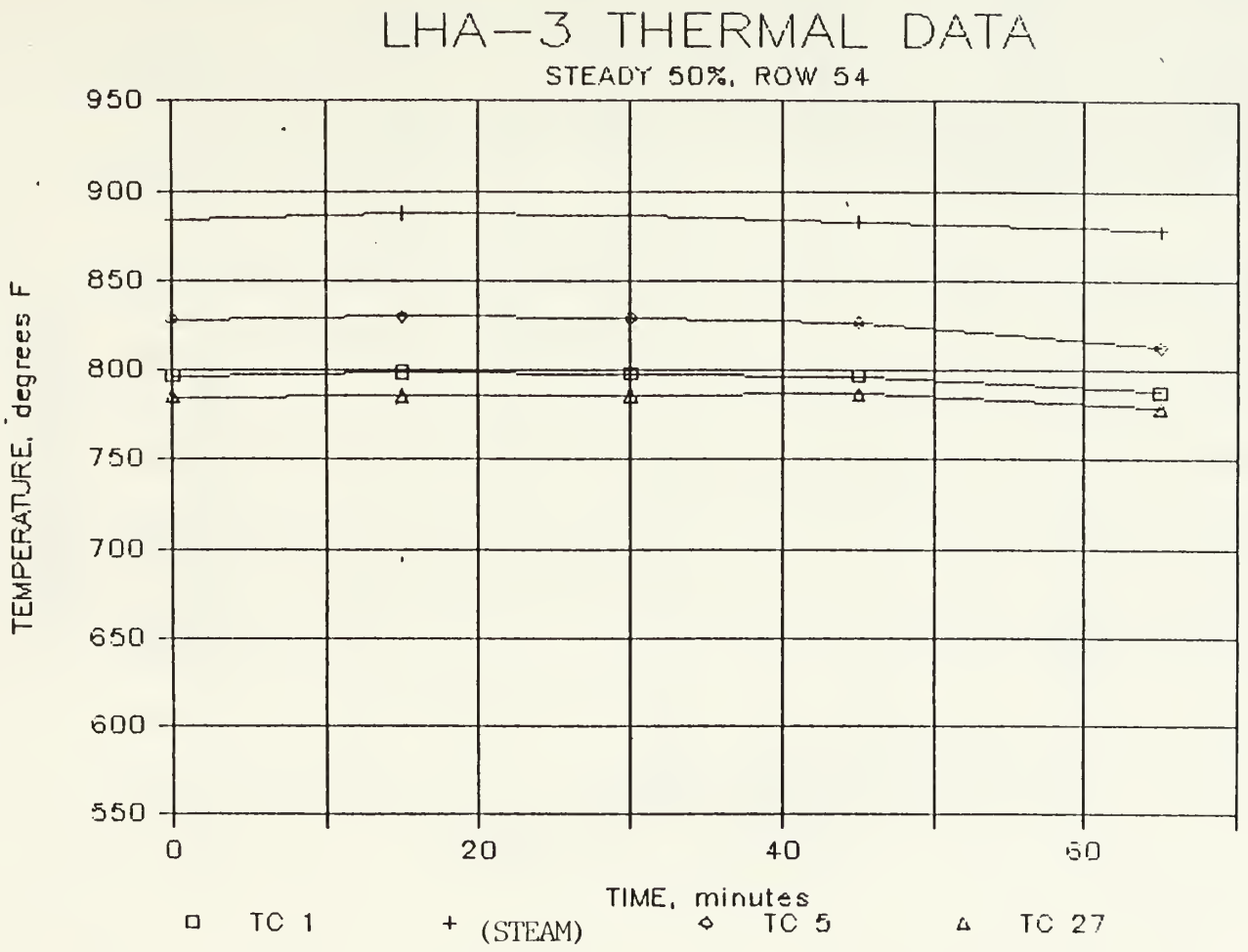
APPENDIX A
TEMPERATURE INSTRUMENTATION DATA FROM THE USS BELLEAU WOOD

SUPERHEATER HEADER CROSS SECTION

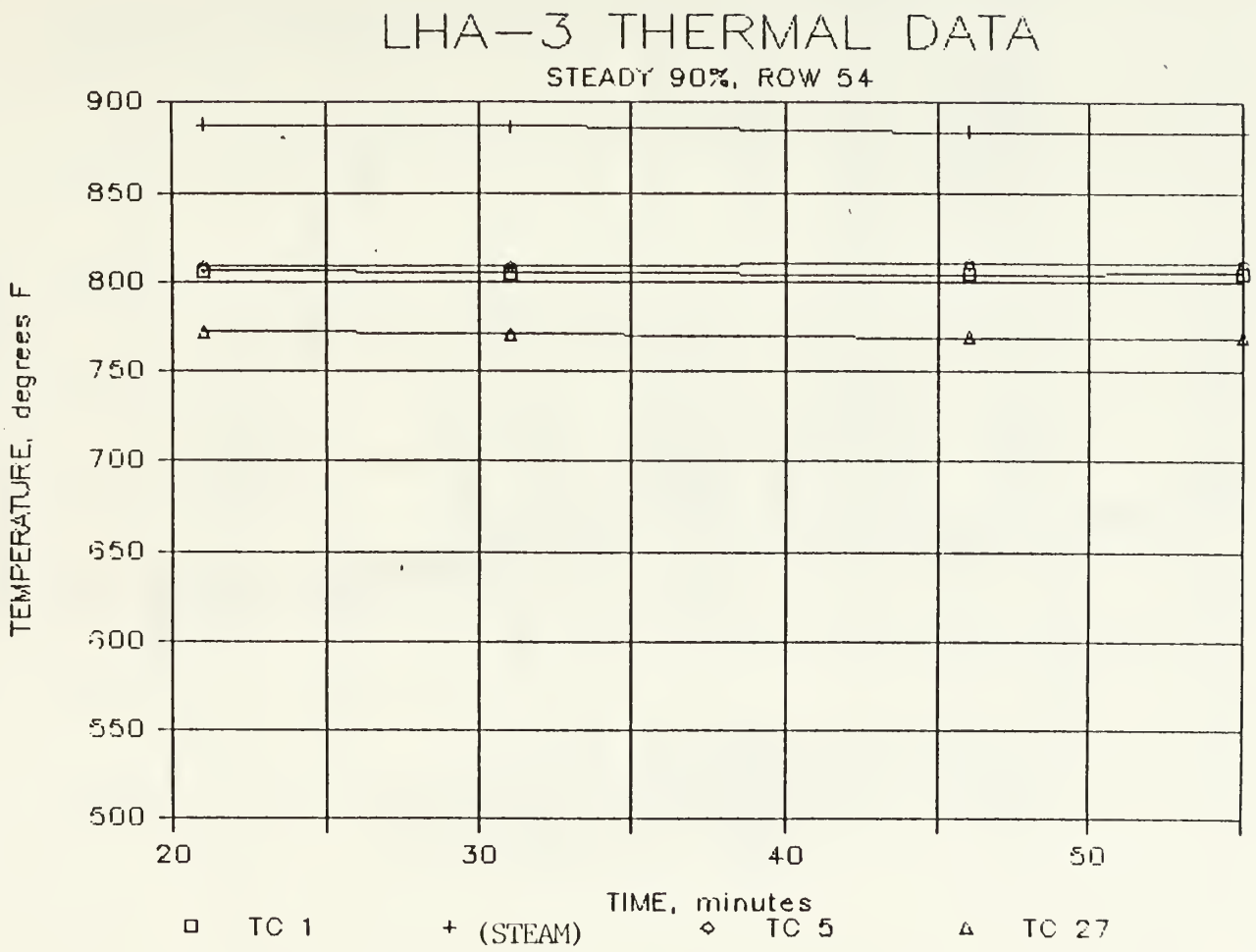


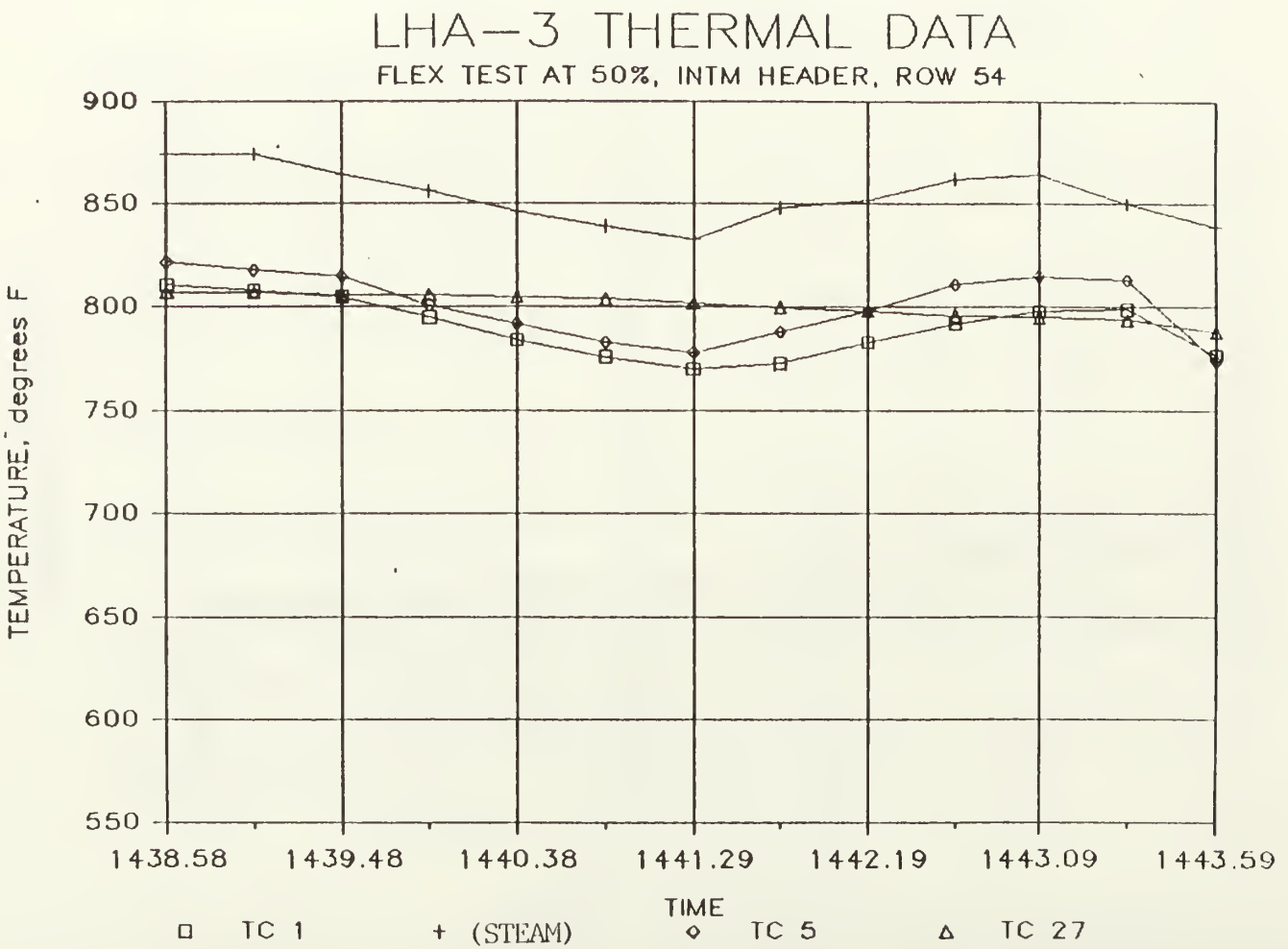

LHA-3 COLD LIGHT-OFF
INTM HEADER, ROW 20, TC'S 1a,5a,27a
TEMPERATURE, degrees F
600
500
400
300
200
100
0
1400 1430 1500 1530 1600 1630 1700 1730 1800 1830 1900
TIME
TC 1a
TC 5a
TC 27a

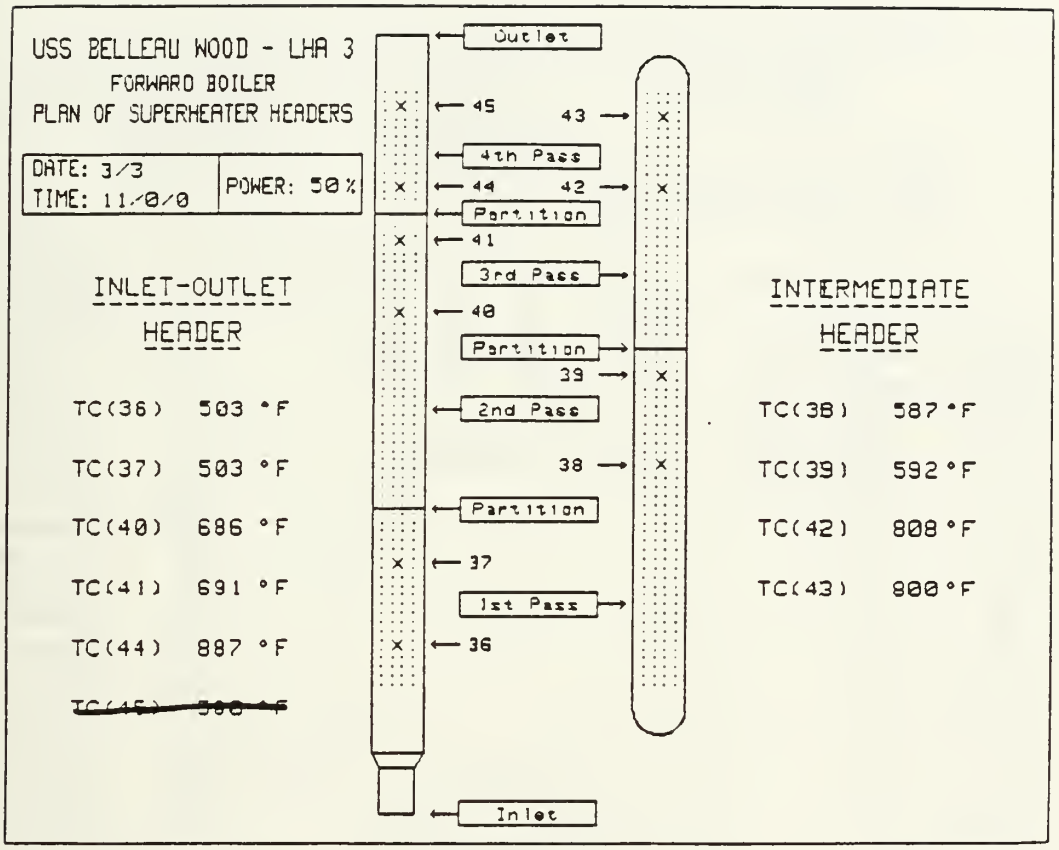

LHA–3 THERMAL DATA
STEADY 25%, ROW 20
950
900
850
800
750
700
650
600
550
TEMPERATURE, degrees F
0831
0846
0901
0916
0931
TIME, hours (military)
TC 1a
(STEAM)
TC 5a
TC 27a

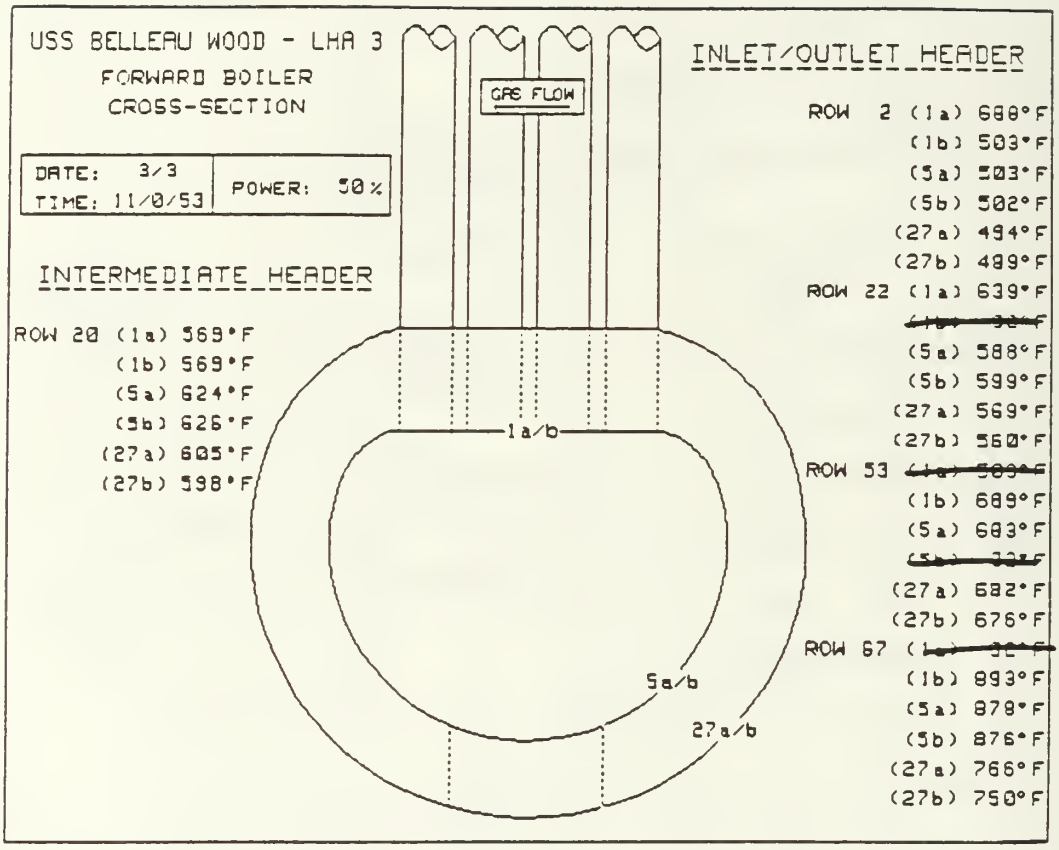

LHA—3 THERMAL DATA
STEADY 50%, ROW 54
TEMPERATURE, degrees F
950
900
850
800
750
700
650
600
550
0
20
40
60
TIME, minutes
TC 1
(STEAM)
TC 5
TC 27

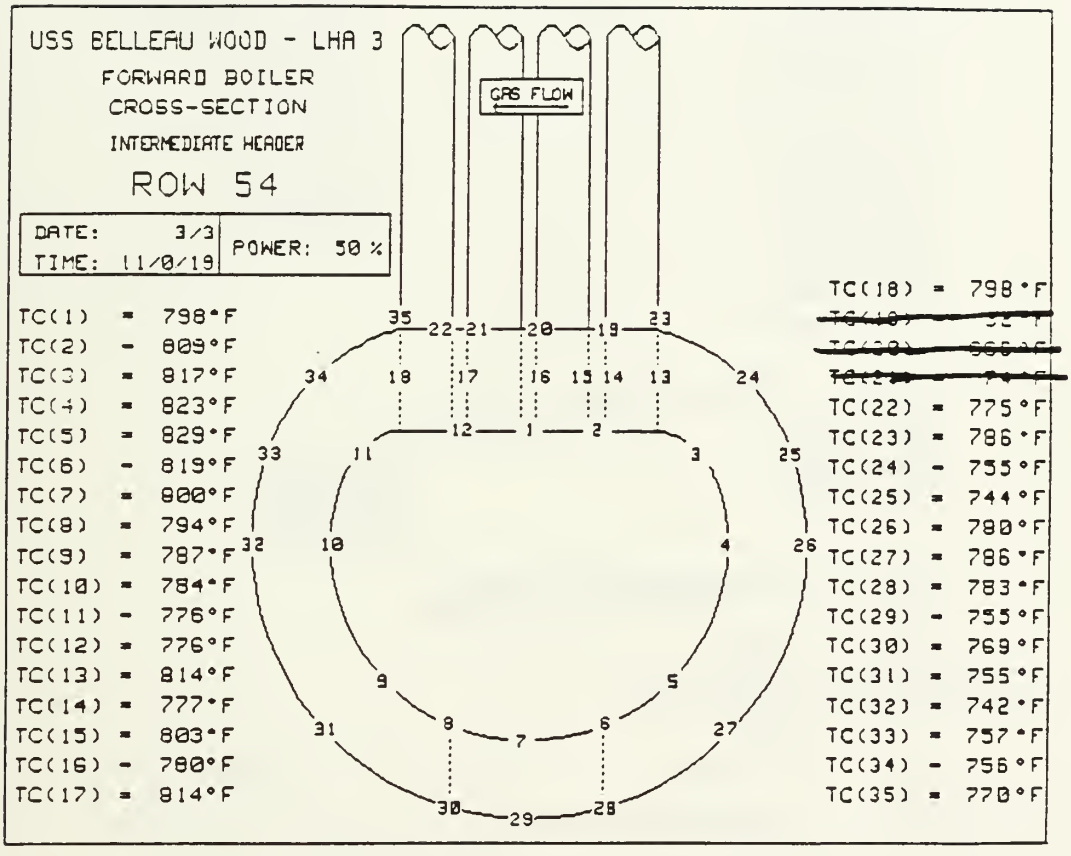
LHA-3 THERMAL DATA
STEADY 75%, ROW 20
TEMPERATURE, degrees F
950
900
850
800
750
700
650
600
550
2215
2230
2300
2315
2330
2345
TIME, hours (military)
□ TC 1a
+ (STEAM)
◇ TC 5a
△ TC 27a


LHA–3 THERMAL DATA
STEADY 90%, ROW 54
TEMPERATURE, degrees F
900
850
800
750
700
650
600
550
500
20
30
40
50
TIME, minutes
TC 1
(STEAM)
TC 5
TC 27


LHA–3 THERMAL DATA
FLEX TEST AT 50%, INTM HEADER, ROW 54
TEMPERATURE, degrees F
900
850
800
750
700
650
600
550
1438.58
1439.48
1440.38
1441.29
1442.19
1443.09
1443.59
TIME
TC 1
(STEAM)
TC 5
TC 27


USS BELLEAU WOOD - LHA 3
FORWARD BOILER
PLAN OF SUPERHEATER HEADERS
DATE: 3/3
TIME: 11/0/0
POWER: 50%
INLET-OUTLET HEADER
TC(36) 503 °F
TC(37) 503 °F
TC(40) 686 °F
TC(41) 691 °F
TC(44) 887 °F
TC(45) 900 °F
Outlet
45
43
4th Pass
44
42
Partition
41
3rd Pass
40
Partition
39
2nd Pass
38
Partition
37
1st Pass
36
Inlet
INTERMEDIATE HEADER
TC(38) 587 °F
TC(39) 592 °F
TC(42) 808 °F
TC(43) 800 °F


USS BELLEAU WOOD - LHA 3
FORWARD BOILER
CROSS-SECTION
DATE: 3/3
TIME: 11/0/53
POWER: 50%
INTERMEDIATE HEADER
ROW 20 (1a) 569°F
(1b) 569°F
(5a) 624°F
(5b) 626°F
(27a) 605°F
(27b) 598°F
GAS FLOW
1a/b
5a/b
27a/b
INLET/OUTLET HEADER
ROW 2 (1a) 688°F
(1b) 503°F
(5a) 503°F
(5b) 502°F
(27a) 494°F
(27b) 489°F
ROW 22 (1a) 639°F
(5a) 588°F
(5b) 599°F
(27a) 569°F
(27b) 560°F
ROW 53
(1b) 689°F
(5a) 683°F
(27a) 682°F
(27b) 676°F
ROW 67
(1b) 893°F
(5a) 878°F
(5b) 876°F
(27a) 766°F
(27b) 750°F


USS BELLEAU WOOD - LHA 3
FORWARD BOILER
CROSS-SECTION
INTERMEDIATE HEADER
ROW 54
DATE: 3/3
TIME: 11/0/19
POWER: 50 %
GAS FLOW
TC(1) = 798°F
TC(2) = 809°F
TC(3) = 817°F
TC(4) = 823°F
TC(5) = 829°F
TC(6) = 819°F
TC(7) = 800°F
TC(8) = 794°F
TC(9) = 787°F
TC(10) = 784°F
TC(11) = 776°F
TC(12) = 776°F
TC(13) = 814°F
TC(14) = 777°F
TC(15) = 803°F
TC(16) = 780°F
TC(17) = 814°F
TC(18) = 798°F
TC(22) = 775°F
TC(23) = 786°F
TC(24) = 755°F
TC(25) = 744°F
TC(26) = 780°F
TC(27) = 786°F
TC(28) = 783°F
TC(29) = 755°F
TC(30) = 769°F
TC(31) = 755°F
TC(32) = 742°F
TC(33) = 757°F
TC(34) = 756°F
TC(35) = 770°F

USS BELLEAU WOOD - LHA 3
FORWARD BOILER

DATE: 3/3 TIME: 11/1/53 POWER 50 %

PHASE 2 - INTERMEDIATE HEADER / ROW 54

TC(1)=797°F
TC(2)=808°F
TC(3)=816°F
TC(4)=822°F
TC(5)=827°F
TC(6)=817°F
TC(7)=800°F
TC(8)=793°F
TC(9)=786°F
TC(10)=783°F
TC(11)=774°F
TC(12)=774°F
TC(13)=813°F
TC(14)=775°F
TC(15)=802°F
TC(16)=779°F
TC(17)=813°F
TC(18)=796°F
[illegible]

TC(22)=774°F
TC(23)=784°F
TC(24)=754°F
TC(25)=745°F
TC(26)=780°F
TC(27)=787°F
TC(28)=783°F
TC(29)=755°F
TC(30)=770°F
TC(31)=756°F
TC(32)=743°F
TC(33)=756°F
TC(34)=756°F
TC(35)=769°F

RHASE 1 - SUPERHEATER HEADER TEMPERATURES

TC(36)=503°F
TC(37)=503°F
TC(38)=585°F
TC(39)=590°F
TC(40)=684°F

TC(41)=690°F
TC(42)=806°F
TC(43)=798°F
TC(44)=883°F
[illegible]

RHASE 3- INTERMEDIATE HEADER TEMPERATURES

ROW 20 (1a) =568°F
ROW 20 (1b) =568°F
ROW 20 (5a) =623°F
ROW 20 (5b) =624°F
ROW 20 (27a)=606°F
ROW 20 (27b)=599°F

PHASE 3- INLET-OUTLET HEADER TEMRERATURE

ROW 2 (1a) =687°F
ROW 2 (1b) =502°F
ROW 2 (5a) =503°F
ROW 2 (5b) =502°F
ROW 2 (27a)=494°F
ROW 2 (27b)=489°F
ROW 22 (1a) =638°F
[illegible]
ROW 22 (5a) =592°F
ROW 22 (5b) =601°F
ROW 22 (27a)=569°F
ROW 22 (27b)=559°F

[illegible]
ROW 53 (1b) =687°F
ROW 53 (5a) =682°F
[illegible]
ROW 53 (27a)=682°F
ROW 53 (27b)=676°F
[illegible]
ROW 67 (1b) =891°F
ROW 67 (5a) =876°F
ROW 67 (5b) =874°F
ROW 67 (27a)=765°F
ROW 67 (27b)=749°F

APPENDIX B
MATERIAL PROPERTY TEST DATA

Chemical Composition and Mechanical Properties

of ASTM A 387, Grade 22 Steel

Chemical Composition

Element	Specification	Analysis[1]
C	0.15 max	0.12
Mn,	0.30 - 0.60	0.42
P	0.03	<0.02
S	0.030	0.03
Si	0.50 max	0.22
Cr	2.00 - 2.50	1.98
Mo	0.90 - 1.20	0.89

Tensile Properties

	Specification	Measured
Yield Strength (0.2%), ksi	30 min	35.3, 33.4
Tensile Strength, ksi	60 - 85	67.2, 69.1
Elongation, %	18 min	38, 37
Reduction of Area, %	—	65, 67

[1]Analysis from Philadelphia Naval Shipyard, M3-194

APPENDIX C
HEADERT INPUT FILE

```
                                    HEADERT                         PAGE #    1

C*************************************************************************************
C
C                                   HEADERT
C                                                BY LT JON W. KAUFMANN  MAY, 1987
C*************************************************************************************
C
C     SOLUTION OF THE HEAT CONDUCTION PROBLEM FOR THE LHA-1 CLASS HEADER
C
C*************************************************************************************
C
C   THE OUTPUT OF THIS PROGRAM IS THE STEADY STATE TEMPERATURES AT EACH OF
C                    THE 1001 NODE POINTS OF THE MODEL
C
C*************************************************************************************
C
C     THE OUTPUT FROM THIS PROGRAM IS READ INTO THE "POTENTIAL"  BLOCK
C                OF THE HEADER PROGRAM PRIOR TO EXECUTION
C
C*****************NUMBER OF NODE POINTS AND LOAD CONDITIONS**********************
C
SYSTEM
N=1001 L=1
:
C*******************DEFINITION OF ACTIVE DEGREES OF FREEDOM**********************
C
RESTRAINTS
1,1001,1     R=1,1,0,1,1,1
C*****************ELEMENT TYPE FOR THE ANALYSIS*********************************
C
ASOLID
 M=1 MAX=1 ATYPE=0
 1 T=1
C**********************MATERIAL PROPERTIES*************************************
C
T=0 E=1    U=0.00    G=1
C*********************ELEMENT DEFINITIONS (CONNECTIVITIES)**********************
C
1 S= 1,4,2           G= 6,1 M=1
7 S= 879,880,894     G= 7,1
14 S= 43,46,44       G= 7,1
21 S=88,101,89       G= 6,6
57 S=257,272,258     G= 12,7
141 S= 632,633,645 G= 6,6
177 S= 963,964,976 G= 6,1
183 S= 924,925,937 G= 6,1
189 S= 840,841,853 G= 6,1
195 S= 801,802,814 G= 6,1
:
C****************CONSTRAINT OF COINCIDENT NODE POINTS**************************
C
CONSTRAINTS
3,36,3       C= 0,88,88,0,0,0      I= 0,13,13,0,0,0
37           C= 0,879,879,0,0,0
38           C= 0,894,894,0,0,0
39           C= 0,617,617,0,0,0
40           C= 0,886,886,0,  ,0
41           C= 0,901,901,0,  ,0
42           C= 0,916,916,0,  ,0
```

```
43              C= 0,893,893,0,0,0
44              C= 0,908,908,0,0,0
45              C= 0,632,632,0,0,0
48,81,3         C= 0,633,633,0,0,0    I= 0,1,1,0,0,0
100,256,13      C= 0,257,257,0,0,0    I= 0,15,15,0,0,0
255             C= 0,452,452,0,0,0
254             C= 0,467,467,0,0,0
253             C= 0,482,482,0,0,0
252             C= 0,497,497,0,0,0
251             C= 0,512,512,0,0,0
250             C= 0,527,527,0,0,0
249             C= 0,542,542,0,0,0
248             C= 0,557,557,0,0,0
247             C= 0,572,572,0,0,0
246             C= 0,587,587,0,0,0
245             C= 0,602,602,0,0,0
451             C= 0,924,924,0,0,0
788             C= 0,924,924,0,0,0
975             C= 0,924,924,0,0,0
1001            C= 0,801,801,0,0,0
950             C= 0,801,801,0,0,0
852             C= 0,801,801,0,0,0
988             C= 0,937,937,0,0,0
865             C= 0,814,814,0,0,0
631             C= 0,632,632,0,0,0
909             C= 0,617,617,0,0,0
244             C= 0,617,617,0,0,0
271             C= 0,963,963,0,0,0
286             C= 0,964,964,0,0,0
301             C= 0,965,965,0,0,0
316             C= 0,966,966,0,0,0
331             C= 0,967,967,0,0,0
346             C= 0,968,968,0,0,0
361             C= 0,969,969,0,0,0
376             C= 0,970,970,0,0,0
391             C= 0,971,971,0,0,0
406             C= 0,972,972,0,0,0
421             C= 0,973,973,0,0,0
436             C= 0,974,974,0,0,0
466             C= 0,775,775,0,0,0
481             C= 0,762,762,0,0,0
496             C= 0,749,749,0,0,0
511             C= 0,736,736,0,0,0
526             C= 0,723,723,0,0,0
541             C= 0,710,710,0,0,0
556             C= 0,697,697,0,0,0
571             C= 0,684,684,0,0,0
586             C= 0,671,671,0,0,0
601             C= 0,658,658,0,0,0
616             C= 0,645,645,0,0,0
989,1000,1      C= 0,840,840,0,0,0    I= 0,1,1,0,0,0
618,630,1       C= 0,910,910,0,0,0    I= 0,1,1,0,0,0
789,800,1       C= 0,925,925,0,0,0    I= 0,1,1,0,0,0
951,962,1       C= 0,802,802,0,0,0    I= 0,1,1,0,0,0
927             C= 0,878,878,0,0,0
:
C***************INPUT AND GENERATION OF NODE POINTS*****************************
C
```

JOINTS

1	Y= .630	Z= 3.000	
2	Y= .661	Z= 3.000	
3	Y= .693	Z= 3.000	
4	Y= .630	Z= 2.987	
6	Y= .698	Z= 2.987	
7	Y= .630	Z= 2.974	
9	Y= .702	Z= 2.974	
10	Y= .630	Z= 2.961	
12	Y= .707	Z= 2.961	
13	Y= .630	Z= 2.948	
15	Y= .712	Z= 2.948	
16	Y= .630	Z= 2.935	
18	Y= .716	Z= 2.935	
19	Y= .630	Z= 2.922	
21	Y= .721	Z= 2.922	
22	Y= .630	Z= 2.909	
24	Y= .726	Z= 2.909	
25	Y= .630	Z= 2.896	
27	Y= .731	Z= 2.896	
28	Y= .630	Z= 2.883	
30	Y= .736	Z= 2.883	
31	Y= .630	Z= 2.870	
33	Y= .740	Z= 2.870	
34	Y= .630	Z= 2.857	
36	Y= .745	Z= 2.857	
37	Y= .630	Z= 2.844	
38	Y= .690	Z= 2.844	
39	Y= .750	Z= 2.844	L= 1,2,12
79	Y= .630	Z= 1.000	G= 37,79,3
80	Y= .690	Z= 1.000	G= 38,80,3
81	Y= .750	Z= 1.000	G= 39,81,3
85	Y= .630	Z= 0.000	G= 79,85,3
86	Y= .690	Z= 0.000	G= 80,86,3
87	Y= .750	Z= 0.000	G= 81,87,3
88	Y= .693	Z= 3.000	
89	Y= .714	Z= 3.010	
90	Y= .735	Z= 3.017	
91	Y= .755	Z= 3.023	
92	Y= .776	Z= 3.026	
93	Y= .797	Z= 3.029	
94	Y= .817	Z= 3.030	
95	Y= .838	Z= 3.029	
96	Y= .858	Z= 3.026	
97	Y= .879	Z= 3.022	
98	Y= .900	Z= 3.016	
99	Y= .921	Z= 3.009	
100	Y= .938	Z= 3.000	
113	Y= .938	Z= 2.995	
126	Y= .938	Z= 2.989	
139	Y= .938	Z= 2.984	
152	Y= .938	Z= 2.975	
165	Y= .938	Z= 2.970	
178	Y= .938	Z= 2.960	
191	Y= .937	Z= 2.952	
204	Y= .933	Z= 2.936	
217	Y= .928	Z= 2.921	
230	Y= .921	Z= 2.906	

```
243 Y= .912    Z= 2.892
256 Y= .901    Z= 2.880
255 Y= .889    Z= 2.869
254 Y= .875    Z= 2.860
253 Y= .860    Z= 2.854
252 Y= .845    Z= 2.848
251 Y= .830    Z= 2.845
250 Y= .813    Z= 2.844
249 Y= .799    Z= 2.844
248 Y= .788    Z= 2.844
247 Y= .778    Z= 2.844
246 Y= .768    Z= 2.844
245 Y= .757    Z= 2.844
244 Y= .750    Z= 2.843
231 Y= .745    Z= 2.857
218 Y= .740    Z= 2.870
205 Y= .736    Z= 2.883
192 Y= .731    Z= 2.896
179 Y= .726    Z= 2.909
166 Y= .721    Z= 2.922
153 Y= .716    Z= 2.935
140 Y= .712    Z= 2.948
127 Y= .707    Z= 2.961
114 Y= .702    Z= 2.974
101 Y= .698    Z= 2.987  L= 88,12,12
257 Y= .938    Z= 3.000
271 Y= 1.200   Z= 3.000  G= 257,271,1
451 Y= 1.200   Z= 2.581  G= 271,451,15
631 Y= .750    Z= 2.581  G= 451,631,15
617 Y= .750    Z= 2.843
630 Y= .750    Z= 2.601  G= 617,630,1
602 Y= .757    Z= 2.844
587 Y= .768    Z= 2.844
572 Y= .778    Z= 2.844
557 Y= .788    Z= 2.844
542 Y= .799    Z= 2.844
527 Y= .813    Z= 2.844
512 Y= .830    Z= 2.845
497 Y= .845    Z= 2.848
482 Y= .860    Z= 2.854
467 Y= .875    Z= 2.860
452 Y= .889    Z= 2.869
437 Y= .901    Z= 2.880
422 Y= .912    Z= 2.892
407 Y= .921    Z= 2.906
392 Y= .928    Z= 2.921
377 Y= .933    Z= 2.936
362 Y= .937    Z= 2.952
347 Y= .938    Z= 2.960
332 Y= .938    Z= 2.970
317 Y= .938    Z= 2.975
302 Y= .938    Z= 2.984
287 Y= .938    Z= 2.989
272 Y= .938    Z= 2.995  L= 257,14,24
632 Y=  .750   Z= 2.581
644 Y=  .750   Z= 1.000  G= 632,644,1
788 Y= 1.200   Z= 2.581  G= 632,788,13
800 Y= 1.200   Z= 1.000  G= 788,800,1
```

```
801 Y= 1.470  Z= 2.581  G= 644,800,13  L= 632,12,12
813 Y= 1.470  Z= 1.000
827 Y= 2.000  Z= 2.581
839 Y= 2.000  Z= 1.000  Q= 801,827,813,839,13,1
840 Y= 1.470  Z= 3.000
852 Y= 1.470  Z= 2.581
866 Y= 2.000  Z= 3.000
878 Y= 2.000  Z= 2.581  Q= 840,866,852,878,13,1
879 Y= .630   Z= 2.844
893 Y= .630   Z= 2.581
909 Y= .750   Z= 2.844
923 Y= .750   Z= 2.581  Q= 879,909,893,923,15,1
924 Y= 1.200  Z= 2.581
950 Y= 1.470  Z= 2.581
936 Y= 1.200  Z= 1.000
962 Y= 1.470  Z= 1.000  Q= 924,950,936,962,13,1
963 Y= 1.200  Z= 3.000
989 Y= 1.470  Z= 3.000
975 Y= 1.200  Z= 2.581
1001 Y= 1.470  Z= 2.581  Q= 963,989,975,1001,13,1
:
C*********************************************************************************
C
C                    INPUT OF BOUNDARY CONDITION TEMPERATURES
C                         ( IN PLACE OF Z DISPLACEMENTS)
C
DISPLACEMENTS
1,85,3      U= 0,0,350
2           U= 0,0,350
3           U= 0,0,350
89,100,1    U= 0,0,350
258,271,1   U= 0,0,350
976         U= 0,0,350
989         U= 0,0,350
853         U= 0,0,350
866         U= 0,0,350
867         U= 0,0,346
868         U= 0,0,342
869         U= 0,0,338
870         U= 0,0,334
871         U= 0,0,330
872         U= 0,0,326
873         U= 0,0,322
874         U= 0,0,318
875         U= 0,0,314
876         U= 0,0,310
877         U= 0,0,306
878         U= 0,0,302
828         U= 0,0,298
829         U= 0,0,294
830         U= 0,0,290
831         U= 0,0,286
832         U= 0,0,282
833         U= 0,0,278
834         U= 0,0,274
835         U= 0,0,270
836         U= 0,0,266
837         U= 0,0,262
838         U= 0,0,258
839         U= 0,0,254
:
```

APPENDIX D
HEADER INPUT FILE

```
C                                    HEADER                                PAGE #    1

C*************************************************************************************
C
C                                    HEADER
C                                              BY LT JON W. KAUFMANN  MAY, 1987
C*************************************************************************************
C
C     STRESS ANALYSIS OF THE LHA-1 CLASS HEADER/TUBE ATTACHMENT WELD JOINT
C
C*************************************************************************************
C
C   THIS PROGRAM STUDIES THE EFFECTS OF TEMPERATURE AND A LONGITUDINAL
C        TUBE LOAD ON THE SUPERHEATER HEADER ATTACHMENT WELD JOINT
C
C*************************************************************************************
C
C*********************NUMBER OF NODE POINTS AND LOAD CONDITIONS*********************
C
SYSTEM
N=1001 L= 3
:
C***************DEFINING THE ACTIVE DEGREES OF FREEDOM*****************************
C
RESTRAINTS
1,1001,1     R=1,0,0,1,1,1
827,839,1    R=1,1,1,1,1,1
866,878,1    R=1,1,1,1,1,1
:
C************************ELEMENT TYPE FOR THE ANALYSIS*****************************
C
ASOLID
 M=1 MAX=1 ATYPE=0 P=1.  T= 0,1.
 1 T=1
C*********************************MATERIAL PROPERTIES*****************************
C
T=0 E=29600 U=.30  A=.0000065
C*********************ELEMENT DEFINITIONS (CONNECTIVITIES)************************

1 S= 1,4,2           G= 6,1 M=1 TZ= 300.0
7 S= 879,880,894     G= 7,1
14 S= 43,46,44       G= 7,1
21 S=88,101,89       G= 6,6
57 S=257,272,258     G= 12,7
141 S= 632,633,645 G= 6,6
177 S= 963,964,976 G= 6,1
183 S= 924,925,937 G= 6,1
189 S= 840,841,853 G= 6,1
195 S= 801,802,814 G= 6,1
:
C*****************CONSTRAINING OF COINCIDENT NODE POINTS************************
C
CONSTRAINTS
3,36,3       C= 0,88,88,0,0,0      I= 0,13,13,0,0,0
37           C= 0,879,879,0,0,0
38           C= 0,894,894,0,0,0
39           C= 0,617,617,0,0,0
40           C= 0,886,886,0,0,0
41           C= 0,901,901,0,0,0
42           C= 0,916,916,0,0,0
```

```
C                                   HEADER                                  PAGE #   2

43          C= 0,893,893,0,0,0
44          C= 0,908,908,0,0,0
45          C= 0,632,632,0,0,0
48,81,3     C= 0,633,0,0,0,0      I= 0,1,0,0,0,0
100,256,13  C= 0,257,257,0,0,0    I= 0,15,15,0,0,0
255         C= 0,452,452,0,0,0
254         C= 0,467,467,0,0,0
253         C= 0,482,482,0,0,0
252         C= 0,497,497,0,0,0
251         C= 0,512,512,0,0,0
250         C= 0,527,527,0,0,0
249         C= 0,542,542,0,0,0
248         C= 0,557,557,0,0,0
247         C= 0,572,572,0,0,0
246         C= 0,587,587,0,0,0
245         C= 0,602,602,0,0,0
451         C= 0,924,924,0,0,0
788         C= 0,924,924,0,0,0
975         C= 0,924,924,0,0,0
1001        C= 0,801,801,0,0,0
950         C= 0,801,801,0,0,0
852         C= 0,801,801,0,0,0
988         C= 0,937,937,0,0,0
865         C= 0,814,814,0,0,0
631         C= 0,632,632,0,0,0
909         C= 0,617,617,0,0,0
244         C= 0,617,617,0,0,0
271         C= 0,963,963,0,0,0
286         C= 0,964,964,0,0,0
301         C= 0,965,965,0,0,0
316         C= 0,966,966,0,0,0
331         C= 0,967,967,0,0,0
346         C= 0,968,968,0,0,0
361         C= 0,969,969,0,0,0
376         C= 0,970,970,0,0,0
391         C= 0,971,971,0,0,0
406         C= 0,972,972,0,0,0
421         C= 0,973,973,0,0,0
436         C= 0,974,974,0,0,0
466         C= 0,775,775,0,0,0
481         C= 0,762,762,0,0,0
496         C= 0,749,749,0,0,0
511         C= 0,736,736,0,0,0
526         C= 0,723,723,0,0,0
541         C= 0,710,710,0,0,0
556         C= 0,697,697,0,0,0
571         C= 0,684,684,0,0,0
586         C= 0,671,671,0,0,0
601         C= 0,658,658,0,0,0
616         C= 0,645,645,0,0,0
989,1000,1  C= 0,840,840,0,0,0    I= 0,1,1,0,0,0
618,630,1   C= 0,910,910,0,0,0    I= 0,1,1,0,0,0
789,800,1   C= 0,925,925,0,0,0    I= 0,1,1,0,0,0
951,962,1   C= 0,802,802,0,0,0    I= 0,1,1,0,0,0
;
C**************************POTENTIAL DATA BLOCK**********************************
C
C       THE RESULTS FROM EXECUTION OF HEADERT ARE INSERTED IN THIS BLOCK
```

```
C                                    HEADER                                PAGE #   3
C
C*****************************************************************************************
C
C*************************PRESSURE LOAD CONDITION*********************************
C
POTENTIAL
1,85,3        P=.700,.700
1,3,1         P=.700,.700
89,100,1      P=.700,.700
258,271,1     P=.700,.700
:
C************************DEFINITON OF LOAD COMBINATIONS*****************************
C
COMBO
1          C= 1,1,1
2          C= 0,1,0
3          C= 0,0,1
4          C= 1,0,0
5          C= 1,1,0
6          C= 0,1,1
:
C*************************LONGITUDINAL TUBE LOAD*********************************
C
C
C
LOADS
85  L= 3  F= 0,0,-0.0253
86  L= 3  F= 0,0,-0.1013
87  L= 3  F= 0,0,-0.0253
:
C************************INPUT AND GENERATION OF NODE POINTS**********************
C
JOINTS
1    Y= .630    Z= 3.000
2    Y= .661    Z= 3.000
3    Y= .693    Z= 3.000
4    Y= .630    Z= 2.987
6    Y= .698    Z= 2.987
7    Y= .630    Z= 2.974
9    Y= .702    Z= 2.974
10   Y= .630    Z= 2.961
12   Y= .707    Z= 2.961
13   Y= .630    Z= 2.948
15   Y= .712    Z= 2.948
16   Y= .630    Z= 2.935
18   Y= .716    Z= 2.935
19   Y= .630    Z= 2.922
21   Y= .721    Z= 2.922
22   Y= .630    Z= 2.909
24   Y= .726    Z= 2.909
25   Y= .630    Z= 2.896
27   Y= .731    Z= 2.896
28   Y= .630    Z= 2.883
30   Y= .736    Z= 2.883
31   Y= .630    Z= 2.870
33   Y= .740    Z= 2.870
34   Y= .630    Z= 2.857
36   Y= .745    Z= 2.857
```

```
37  Y= .630   Z= 2.844
38  Y= .690   Z= 2.844
39  Y= .750   Z= 2.844  L= 1,2,12
79  Y= .630   Z= 1.000  G= 37,79,3
80  Y= .690   Z= 1.000  G= 38,80,3
81  Y= .750   Z= 1.000  G= 39,81,3
85  Y= .630   Z= 0.000  G= 79,85,3
86  Y= .690   Z= 0.000  G= 80,86,3
87  Y= .750   Z= 0.000  G= 81,87,3
88  Y= .693   Z= 3.000
89  Y= .714   Z= 3.010
90  Y= .735   Z= 3.017
91  Y= .755   Z= 3.023
92  Y= .776   Z= 3.026
93  Y= .797   Z= 3.029
94  Y= .817   Z= 3.030
95  Y= .838   Z= 3.029
96  Y= .858   Z= 3.026
97  Y= .879   Z= 3.022
98  Y= .900   Z= 3.016
99  Y= .921   Z= 3.009
100 Y= .938   Z= 3.000
113 Y= .938   Z= 2.995
126 Y= .938   Z= 2.989
139 Y= .938   Z= 2.984
152 Y= .938   Z= 2.975
165 Y= .938   Z= 2.970
178 Y= .938   Z= 2.960
191 Y= .937   Z= 2.952
204 Y= .933   Z= 2.936
217 Y= .928   Z= 2.921
230 Y= .921   Z= 2.906
243 Y= .912   Z= 2.892
256 Y= .901   Z= 2.880
255 Y= .889   Z= 2.869
254 Y= .875   Z= 2.860
253 Y= .860   Z= 2.854
252 Y= .845   Z= 2.848
251 Y= .830   Z= 2.845
250 Y= .813   Z= 2.844
249 Y= .799   Z= 2.844
248 Y= .788   Z= 2.844
247 Y= .778   Z= 2.844
246 Y= .768   Z= 2.844
245 Y= .757   Z= 2.844
244 Y= .750   Z= 2.843
231 Y= .745   Z= 2.857
218 Y= .740   Z= 2.870
205 Y= .736   Z= 2.883
192 Y= .731   Z= 2.896
179 Y= .726   Z= 2.909
166 Y= .721   Z= 2.922
153 Y= .716   Z= 2.935
140 Y= .712   Z= 2.948
127 Y= .707   Z= 2.961
114 Y= .702   Z= 2.974
101 Y= .698   Z= 2.987  L= 88,12,12
257 Y= .938   Z= 3.000
```

```
271 Y= 1.200   Z= 3.000   G= 257,271,1
451 Y= 1.200   Z= 2.581   G= 271,451,15
631 Y= .750    Z= 2.581   G= 451,631,15
617 Y= .750    Z= 2.843
630 Y= .750    Z= 2.601   G= 617,630,1
602 Y= .757    Z= 2.844
587 Y= .768    Z= 2.844
572 Y= .778    Z= 2.844
557 Y= .788    Z= 2.844
542 Y= .799    Z= 2.844
527 Y= .813    Z= 2.844
512 Y= .830    Z= 2.845
497 Y= .845    Z= 2.848
482 Y= .860    Z= 2.854
467 Y= .875    Z= 2.860
452 Y= .889    Z= 2.869
437 Y= .901    Z= 2.880
422 Y= .912    Z= 2.892
407 Y= .921    Z= 2.906
392 Y= .928    Z= 2.921
377 Y= .933    Z= 2.936
362 Y= .937    Z= 2.952
347 Y= .938    Z= 2.960
332 Y= .938    Z= 2.970
317 Y= .938    Z= 2.975
302 Y= .938    Z= 2.984
287 Y= .938    Z= 2.989
272 Y= .938    Z= 2.995   L= 257,14,24
632 Y=  .750   Z= 2.581
644 Y=  .750   Z= 1.000   G= 632,644,1
788 Y= 1.200   Z= 2.581   G= 632,788,13
800 Y= 1.200   Z= 1.000   G= 788,800,1
801 Y= 1.470   Z= 2.581   G= 644,800,13  L= 632,12,12
813 Y= 1.470   Z= 1.000
827 Y= 2.000   Z= 2.581
839 Y= 2.000   Z= 1.000   Q= 801,827,813,839,13,1
840 Y= 1.470   Z= 3.000
852 Y= 1.470   Z= 2.581
866 Y= 2.000   Z= 3.000
878 Y= 2.000   Z= 2.581   Q= 840,866,852,878,13,1
879 Y= .630    Z= 2.844
893 Y= .630    Z= 2.581
909 Y= .750    Z= 2.844
923 Y= .750    Z= 2.581   Q= 879,909,893,923,15,1
924 Y= 1.200   Z= 2.581
950 Y= 1.470   Z= 2.581
936 Y= 1.200   Z= 1.000
962 Y= 1.470   Z= 1.000   Q= 924,950,936,962,13,1
963 Y= 1.200   Z= 3.000
989 Y= 1.470   Z= 3.000
975 Y= 1.200   Z= 2.581
1001 Y= 1.470  Z= 2.581   Q= 963,989,975,1001,13,1
:
```

APPENDIX E
EXCERPT FROM ASME BOILER CODE

TABLE PG-23.1 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES FOR FERROUS MATERIALS, ksi
(Multiply by 1000 to Obtain psi)

Nominal Composition	Product Form	Spec. Number	Grade or Class	Notes	Specified Minimum Tensile	For Metal Temperatures Not Exceeding °F: -20 to 100	200	300	400	-20 to 400	500	600	650
Low Alloy Steels (Cont'd)													
1¼Cr-½Mo-Si	Forg.	SA-182	F11	...	70.0	...	...	...	...	17.5	17.5	17.5	17.5
1¼Cr-½Mo-Si	Plate	SA-387	11Cl.2	(4)	75.0	...	...	...	...	18.8	18.8	18.8	18.8
1¼Cr-½Mo	Cast.	SA-217	WC6	(4)(5)	70.0	...	...	...	...	17.5	17.5	17.5	17.5
2Cr-½Mo	Smls. Tb.	SA-213	T3b	...	60.0	...	...	...	...	15.0	15.0	14.7	14.4
2Cr-½Mo	Smls. Pp.	SA-369	FP3b	...									
2¼Cr-1Mo	Plate	SA-387	22Cl.1	...	60.0	...	...	...	...	15.0	15.0	15.0	15.0
2¼Cr-1Mo	Smls. Tb.	SA-213	T22	...									
2¼Cr-1Mo	Smls. Pp.	SA-335	P22	...									
2¼Cr-1Mo	Forg.	SA-336	F22a	...									
2¼Cr-1Mo	Smls. Pp.	SA-369	FP22	...									
2¼Cr-1Mo	Forg.	SA-182	F22a	...									
2¼Cr-1Mo	Fittings	SA-234	WP22	(20)									
2¼Cr-1Mo	Cast.	SA-217	WC9	(4)(5)	70.0	17.5	17.5	17.3	16.9	...	16.8	16.8	16.7
2¼Cr-1Mo	Forg.	SA-182	F22	...	75.0	18.8	18.8	18.3	18.0	...	17.9	17.8	17.7
2¼Cr-1Mo	Plate	SA-387	22Cl.2	(4)									
2¼Cr-1Mo	Forg.	SA-336	F22	...									
3Cr-1Mo	Plate	SA-387	21Cl.1	...	60.0	...	...	...	...	15.0	15.0	15.0	15.0
3Cr-1Mo	Smls. Tb.	SA-213	T21	...									
3Cr-1Mo	Smls. Pp.	SA-335	P21	...									
3Cr-1Mo	Forg.	SA-336	F21a	...									
3Cr-1Mo	Smls. Pp.	SA-369	FP21	...									
3Cr-1Mo	Forg.	SA-182	F21	...	75.0	18.8	18.8	18.3	18.0	...	17.9	17.8	17.7
3Cr-1Mo	Plate	SA-387	21Cl.2	(4)									
3Cr-1Mo	Forg.	SA-336	F21	...									
5Cr-½Mo	Fittings	SA-234	WP5	(20)	60.0	15.0	15.0	14.5	14.4	...	14.4	14.1	13.9
5Cr-½Mo	Plate	SA-387	5	...									
5Cr-½Mo	Smls. Tb.	SA-213	T5	...									
5Cr-½Mo	Smls. Pp.	SA-335	P5	...									
5Cr-½Mo	Smls. Pp.	SA-369	FP5	...									
5Cr-½Mo	Forg.	SA-336	F5	...									
5Cr-½Mo-Si	Smls. Tb.	SA-213	T5b	...									
5Cr-½Mo-Si	Smls. Pp.	SA-335	P5b	...									
5Cr-½Mo-Ti	Smls. Tb.	SA-213	T5c	...									
5Cr-½Mo-Ti	Smls. Pp.	SA-335	P5c	...									
5Cr-½Mo	Forg.	SA-182	F5	...	70.0	17.5	17.5	17.0	16.8	...	16.8	16.5	16.3
5Cr-½Mo	Forg.	SA-336	F5a	...	80.0	20.0	20.0	19.4	19.2	...	19.2	18.7	18.6
5Cr-½Mo	Forg.	SA-182	F5a	...	90.0	22.5	22.4	21.8	21.6	...	21.6	21.3	20.9
5Cr-½Mo	Cast.	SA-217	C5	(4)(5)	90.0	22.5	22.4	21.8	21.6	...	21.6	21.3	20.9

TABLE PG-23.1 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES FOR FERROUS MATERIALS, ksi
(Multiply by 1000 to Obtain psi)

For Metal Temperatures Not Exceeding °F																	Spec.	Grade
700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	Number	or Class
																		Low Alloy Steels (Cont'd)
17.5	17.5	17.5	17.1	15.9	11.0	6.9	4.6	2.8	(2.1)	(1.2)	. . .	. . .	. . .	. . .	. . .	. . .	SA-182	F11
18.8	18.8	18.8	18.3	15.9	11.0	6.9	4.6	2.8	(2.1)	(1.2)	. . .	. . .	. . .	. . .	. . .	. . .	SA-387	11Cl.2
17.5	17.5	17.5	17.1	15.9	11.0	6.9	4.6	2.8	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	SA-217	WC6
																	SA-213	T3b
14.2	13.9	13.5	13.1	12.5	10.0	6.2	4.2	2.6	(1.4)	(1.0)	. . .	. . .	. . .	. . .	. . .	. . .	SA-369	FP3b
																	SA-387	22Cl.1
																	SA-213	T22
																	SA-335	P22
15.0	15.0	15.0	14.4	13.1	11.0	7.8	5.8	4.2	(3.0)	(1.6)	. . .	. . .	. . .	. . .	. . .	. . .	SA-336	F22a
																	SA-369	FP22
																	SA-182	F22a
																	SA-234	WP22
16.6	16.1	15.7	15.0	14.2	11.0	7.6	5.8	4.4	(2.5)	(1.3)	. . .	. . .	. . .	. . .	. . .	. . .	SA-217	WC9
																	SA-182	F22
17.5	17.2	16.9	16.4	15.8	11.0	7.6	5.8	4.4	(2.5)	(1.3)	. . .	. . .	. . .	. . .	. . .	. . .	SA-387	22Cl.2
																	SA-336	F22
																	SA-387	21Cl.1
																	SA-213	T21
14.8	14.5	13.9	13.2	12.0	9.0	7.0	5.5	4.0	(2.7)	(1.5)	. . .	. . .	. . .	. . .	. . .	. . .	SA-335	P21
																	SA-336	F21a
																	SA-369	FP21
																	SA-182	F21
17.5	17.2	16.9	16.4	13.1	9.5	6.8	4.9	3.2	(2.4)	(1.3)	. . .	. . .	. . .	. . .	. . .	. . .	SA-387	21Cl.2
																	SA-336	F21
																	SA-234	WP5
																	SA-387	5
																	SA-213	T5
																	SA-335	P5
																	SA-369	FP5
13.7	13.2	12.8	12.1	10.9	8.0	5.8	4.2	2.9	2.0	1.3	. . .	. . .	. . .	. . .	. . .	. . .	SA-336	F5
																	SA-213	T5b
																	SA-335	P5b
																	SA-213	T5c
																	SA-335	P5c
16.0	15.4	14.9	14.1	10.8	8.0	5.8	4.2	2.9	2.0	1.3	. . .	. . .	. . .	. . .	. . .	. . .	SA-182	F5
18.2	17.6	17.0	14.3	10.8	8.0	5.8	4.2	2.9	2.0	1.3	. . .	. . .	. . .	. . .	. . .	. . .	SA-336	F5a
20.5	19.8	19.1	14.8	10.8	8.0	5.8	4.2	2.9	2.0	1.3	. . .	. . .	. . .	. . .	. . .	. . .	SA-182	F5a
20.5	19.8	19.1	14.3	10.9	8.0	5.8	4.2	2.9	2.0	1.3	. . .	. . .	. . .	. . .	. . .	. . .	SA-217	C5

APPENDIX F
PROJECTED BOILER OPERATING CYCLE (CV-60 CLASS)

No. of cycles	Type of pressure/temperature cycle
1	150% design pressure hydro
3	125% max. operating pressure hydro
60	100% max. operating pressure hydro
150	cold (0 psi) to operating pressure and temperature
150	steam blanket (150 psi) to operating pressure and temperature
225	cold (0 psi) to steam blanket (150 psi)
300	125 psi variation at operating pressure and temperature

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16. LT Jon W. Kaufmann, USN — 5
10 Sycamore Drive
Roslyn, NY 11576

Thesis
K1486 Kaufmann
c.1 Stress analysis of the LHA-1 class superheater header by finite element method.